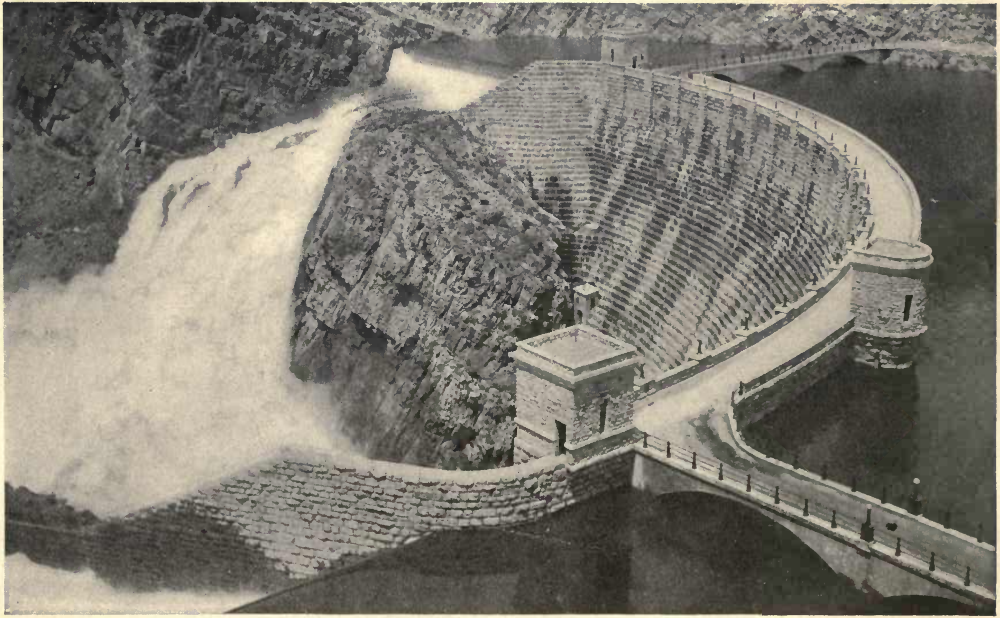

FIG. 1.—Roosevelt Dam, looking north.

IRRIGATION WORKS

CONSTRUCTED BY THE

UNITED STATES GOVERNMENT

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Dedicated to

JOHN W. POWELL,
THE FAR-SEEING PHILOSOPHER;
FRANCIS G. NEWLANDS,
THE CONSTRUCTIVE STATESMAN; AND
FREDERICK H. NEWELL,
THE FAITHFUL ADMINISTRATOR;
THE PIONEERS WHO BLAZED THE WAY
FOR THE BENEFICENT WORK OF
NATIONAL RECLAMATION

PREFACE

AGRICULTURE by irrigation is one of the oldest occupations of civilized man. Various parts of the world show evidences that irrigation was practised long before any historical record was kept. The remains of prehistoric irrigation works have been identified and extensively traced in southern Arizona along the Salt River and in parts of New Mexico and California.

American Irrigation was left entirely to private and corporate enterprise until the passage, in 1902, of the National Reclamation Act, which has been amended and modified from time to time by subsequent acts.

The original reclamation act provided for the segregation of the receipts from the sales of public lands in the sixteen Western States and Territories into a special fund to be known as the Reclamation Fund and to be available for the survey, construction, and operation of reclamation projects in those States. It provided that the cost of those projects should be returned to the Reclamation Fund by the owners of private land or entrymen on public land in ten annual installments, no requirement of interest being made. A subsequent act in 1914 extended this time to twenty years. The original act required the expenditure of the major portion of the funds in the States in which it had been received. Under this act about one hundred million dollars have been expended in construction, and twenty-five projects are now in operation and prepared to deliver water to about one million five hundred thousand acres of land, about two-thirds of which was actually irrigated in 1916.

The projects undertaken, unlike the early simple diversions upon valleys adjacent to the headworks, involved, on the contrary, expensive storage works, high diversion dams, difficult tunnels, or long, expensive canal work upon side hills, where large investment was necessary before any water was brought to the land. Many projects discussed in the early days of the reclamation work were rejected by the Reclamation Service because they

were deemed within the reach of private investment. Some of those same projects were afterward taken up by the Government after years of unsuccessful effort to enlist private capital in their construction.

Inasmuch as all expenses connected with this work are charged to the water users, care is taken to incur no expenditure not absolutely necessary for the work, and this rule applied to the publication of annual reports excludes everything not absolutely required by law, consequently excluding the engineering descriptions of the work and the illustrations which this would require. It is the object of the present work to supply this need for the information of the engineering profession, and of statesmen and others interested in the development of the arid lands.

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IRRIGATION WORKS CONSTRUCTED BY U. S. GOVERNMENT

CHAPTER I

INTRODUCTION

As a modern activity of the Caucasian race, irrigation in the United States on any considerable scale seems to have had its beginning in Utah in the settlement of the Salt Lake Valley. The early settlements of California, New Mexico, and other arid States extended the practice of the early Spaniards and the Indians, and irrigation developed along with the slow settlement of these then remote regions.

During the early history of irrigation farmers and groups of farmers naturally confined their efforts mainly to diverting small streams upon adjacent valleys where the slope of the country and the topography were such as to make the work easy and cheap. With the values of land then existing no expensive enterprise was practicable. Such development proceeding for nearly half a century, widely distributed over the arid region, irrigated in the aggregate a very large area of land. The farmers employed the cheapest class of construction and seldom counted their own time in computing costs, which are hence reported very low.

As land values increased and the easier projects had been developed, more difficult ones were taken up, sometimes successfully and sometimes not. As the difficult problems were attacked, corporate capital and the district system were employed, and such projects as they could handle were gradually developed. The inherent difficulties, however, did not admit of much profit to the investor. In fact, in a majority of the cases, the investors lost a large part of their capital, to say nothing of interest and profits, and though the general benefits in the development of the country were great and lasting, the losses made it more and more difficult to enlist private capital in further irrigation enterprise.

Various laws were passed from time to time to encourage the irrigation of arid lands, the desert-land act and the Carey Act, with their various modifications, being the most conspicuous examples, depending upon the investment of private or corporate capital for actual construction.

The increasing difficulty of carrying out many large projects led to the passage in 1902 of the reclamation act, with the avowed and widely heralded object of enlisting national funds for the development of projects not feasible by private, corporate, district, or State enterprise. This policy, avowed in Congress and announced repeatedly by the President, was followed by the Reclamation Service.

The projects undertaken, unlike the early simple diversions upon valleys adjacent to the headworks, involved, on the contrary, expensive storage works, high diversion dams, difficult tunnels, or long, expensive canal work upon side hills, where large investment was necessary before any water was brought to the land. Many projects discussed in the early days of the reclamation work were rejected by the Reclamation Service because they were deemed within the reach of private investment. Some of those same projects were afterward taken up by the Government after years of unsuccessful effort to enlist private capital in their construction.

Practically all of the projects undertaken by the Reclamation Service had been abandoned after unsuccessful attempts to finance them as private projects, or else were new projects so difficult as not to attract even the attention of promoters.

Prior to the passage of the reclamation act the hydrographic branch of the Geological Survey had undertaken surveys of some of the larger and more intricate projects suggested and had made some stream measurements to shed light upon their feasibility. After the passage of the reclamation act this work was greatly expanded and data were rapidly accumulated from which projects were outlined and estimates made, mainly in the years 1902, 1903, and 1904. By this time the program had become crystallized, by which one or more projects in nearly all of the arid States had been undertaken or examined with a view to their early construction. The estimates upon which these projects were based were necessarily the accumulated experience upon work of a similar kind which had been carried out within the

previous decade. The estimates were, therefore, made upon the basis of work done during the period of depression and low prices from 1892 to 1902. The estimates were made at a time when the country was entering upon a period of rising prices, which, however, was not foreseen by those concerned. The result was that the years 1905, 1906, 1907, and 1908, in which most of the construction work was done, were coincident with a great boom in railroad construction throughout the West, the reconstruction of the City of San Francisco after the fire, and a corresponding expansion of other construction work throughout the arid regions. Unavoidably, therefore, much of the work cost more than could have been foreseen from the experience of the previous decade. The increased cost of living during the past two decades is a rough index to the increased cost of construction. The cost of railroad and irrigation work carried out by private enterprise in the West increased in the same period from 50 to 100 per cent.

The work so far has resulted in the provision of reservoirs, carriage and distributing systems, and other works by which the United States is prepared to deliver water to 1,680,000 acres of land, of which 950,000 were actually irrigated by settlers in 1916, and this area is considerably increased during the present year. The annual product of this acreage is estimated at over $22,000,000, and a large number of prosperous homes have been established and many towns and villages have sprung up.

The Reclamation Service has had an exceptional opportunity for developing and trying on a large scale many ideas and methods in hydraulic construction. While it has endeavored to be conservative in everything which involves risk, yet, wherever possible, the effort has been made to adopt the latest and best in design and construction.

The question may be raised at the outset whether these works, built with funds provided by the Government, are of such character that they can be considered as typical or suggestive for private or corporate effort. In answer to this it may properly be claimed that although large funds were available, yet in the organization and conduct of the work, from its initiation, every reasonable safeguard was adopted to secure economy and efficiency in construction. A system of cost keeping was instituted fully up with the times, and the engineers in charge of the work

at all times have felt a professional and personal pride in showing that they could, and did, execute these difficult operations in remote localities and under pioneer conditions not only well, but economically. It is true that in any public work there are certain conditions inseparably connected with Governmental methods which tend to add to the cost, such, for example, as those growing out of changing administrations with varying policies—frequent and often unfriendly investigations, the delays which result from legal complications and the imperfectly devised civil service employment schemes, the complications in the auditing and handling of public funds, and because of many other conditions which result from the fact that in Government work clerical and legal details are often more highly esteemed than ultimate results, or, as popularly expressed, "Efficiency is held down by red tape."

Notwithstanding this condition, which under the peculiar organization of the Reclamation Service has been kept to a minimum, the engineers and others connected with this work feel a proper pride not only in its performance, but in the economy with which the work as a whole has been performed.

One of the most notable features connected with this work, from the standpoint of organization, is the fact that these works are widely distributed. The engineering features of the Reclamation Service presented greater difficulties than most large works because of their variety and wide distribution throughout the Western part of the United States. Each project had its peculiar problems and required special and individual treatment. The work was not an enlargement or duplication of units and organization on a grand scale, where one man could see nearly every part of the work in a day, but, on the contrary, was of such a nature that no one man could see all of the important features even in continuous travel for months.

A serious handicap to the prompt construction of reclamation projects authorized by the law of 1902 was the paucity of data concerning the water supply upon which they must depend.

A considerable amount of data had been collected by the hydrographic branch of the Geological Survey in the decade previous to the passage of the Act, but the greater part of this was in the East, to which the Reclamation Law did not apply.

The relatively small amount of data on stream flow that did exist in the West was, however, invaluable so far as it went, and constituted practically the only available water data upon which to undertake these works. The topographic maps of the Geological Survey were of great value wherever they existed, but these again were completed for only a small portion of the arid regions.

The so-called irrigation branch of the Geological Survey in 1889 and 1890 made a few preliminary investigations of proposed irrigation projects, but these were scarcely started before they were stopped for lack of appropriation, and very little of the data collected thereby could be used, except the stream measurements and topographic maps above referred to.

The work laid out for the Reclamation Service was nearly unprecedented. While a considerable area of lands had been irrigated in the West, this was confined mainly to the diversion of the natural flow of small streams in open valleys, and the new work contemplated was intended to develop those works which were more difficult, requiring much heavy construction, high diversion dams, tunnels, long side-hill canals through rough country, and large storage reservoirs.

Practically the only existing precedents were a few private works crudely built and mostly failures through lack of necessary capital, and a few municipal reservoirs adjacent to large cities in various parts of the world. These latter, however, owing to the high value of water for domestic use, were not confined to the limitations of cost that characterize investments for irrigation, and though in some details would serve as engineering precedents, they were more often misleading than valuable precedents in an economic sense.

The data incorporated in this work are obtained from personal acquaintance, official reports, and various articles written by the men concerned.

The author has been materially assisted, directly or indirectly, by nearly all the men holding responsible positions during the last ten years in the Reclamation Service. These are mentioned specifically in connection with the work with which they were concerned, but more general acknowledgment is due to Professor F. H. Newell, former director of the Reclamation Service, for valuable co-operation and advice, and to Mr. E. A. Moritz, who wrote the description of the Sunnyside Project in its entirety.

CHAPTER II

SALT RIVER PROJECT

HISTORY

Salt River Valley is that territory lying adjacent to Salt River, extending from the point where it emerges from the mountains near the mouth of Verde River, its principal tributary, to the mouth of Salt River, where it joins the Gila. Irrigation on a large scale was carried on in this valley in prehistoric times by some ancient race, whose canal lines have been nearly obliterated by time, being now discernible with difficulty. The river has a good fall, so that water can be diverted at almost any point and carried diagonally away from the stream, covering considerable land in a short distance. The first diversion of Salt River by white men was in 1868, through the Salt River Valley Canal, built by Jack Swilling and his associates.

The canals built by private enterprise are listed in the following table:

PRINCIPAL CANALS OF SALT RIVER VALLEY

	Length, Miles	When First Used
North Side		
Arizona	47	1885
Grand	27	1878
Maricopa	26	1868
Salt River Valley	19	1868
Farmers	5	....
St. Johns	12	....
South Side		
Highland	22	1889
Consolidated	40	1894
Old Mesa	10	1878
Utah	20	1877
Tempe	30	1871
San Francisco	6	1871

The combined capacity of these canals was far in excess of the normal low-water flow of the river, their construction being

induced by a superficial consideration of the series of years of abnormally high run-off between 1888 and 1897. Following that period the reverse occurred, a period of abnormally low run-off, continuing for over six years, and this drouth led to the death of valuable orchards, vineyards, and alfalfa fields, and to active efforts by the people to secure the construction of storage reservoirs.

In 1901 the Legislature of Arizona provided for preliminary investigations of the feasibility of water storage on upper Salt River, which were carried out in co-operation with the Geological Survey under direction of the author in 1901.

The first report on preliminary investigations was published as water-supply paper No. 73 of the Geological Survey. This report contemplated the construction of a reservoir with county or district bonds, and it was therefore necessary to plan it as cheaply as possible. The reservoir there proposed was about one-half the capacity of the one finally built, and no provision was made for the development of a permanent power supply. The subsequent availability of the Reclamation Fund led to more comprehensive plans. The reservoir was planned about twice as large and a large power development for future use was included.

ROOSEVELT RESERVOIR

The original purpose of the Reclamation Service was simply to build a large reservoir, leaving the companies and associations operating the canals to enlarge and extend them as needed for the delivery of additional water supply. A great flood in 1905, however, destroyed the diversion dam and otherwise injured the works of the Arizona Water Company, which controlled all the canals on the north side of Salt River. The inability of the company to repair the works promptly led to their purchase by the Secretary of the Interior, who thereby undertook to reconstruct the diversion and distribution system.

As worked out, the Salt River Project includes a storage reservoir, a large concrete diverting dam, with sluices and headworks on each side of the river, a complete system of canals and laterals to cover over 200,000 acres of land, a power-plant at the Roosevelt Dam with a transmission line to bring the power to the valley below, for use in pumping underground waters and for other purposes.

AREA AND CAPACITY OF ROOSEVELT RESERVOIR

*Depth, Feet	Surface, Acres	Capacity, in Acre Feet
10	24	120
20	128	880
30	224	2,640
40	401	5,765
50	694	11,241
60	1,085	20,135
70	1,458	32,850
80	2,103	50,655
90	2,930	75,820
100	3,682	108,880
110	4,391	149,245
120	5,536	198,880
130	6,394	258,530
140	7,293	326,965
150	8,411	405,485
160	9,664	495,860
170	10,769	598,025
180	12,158	712,660
190	13,459	840,775
200	14,192	979,000
210	15,260	1,126,260
220	16,329	1,284,200
225	16,832	1,367,300

* Spillway Crest Elevation, 225.

Roosevelt Dam.—The storage dam is located in a gorge about 72 miles above Phœnix, just below the junction of Tonto Creek with Salt River. It submerges a portion of "Tonto Basin," a region long famous in the early history of Arizona as a refuge for outlaws, on account of its relative inaccessibility. It is surrounded in all directions by mountains and plateaus scored by numerous profound canyons, Salt River itself being in a box canyon for a distance of forty miles below. and a greater distance above, this point.

The dam is of rubble masonry with coursed rubble faces, laid in Portland cement mortar, and vertical joints filled with concrete. It is 240 feet in height above the natural river-bed, and the foundation is carried about 40 feet below that point to solid rock. Fifteen feet below the top of the dam is a spillway, to carry surplus water to the river-bed well below the dam. The section of the dam, as shown in Figure 1, is such that, considered as a gravity structure, the limit of pressure upon the base is 18.9 tons per square foot on the horizontal joint. The dam is 16 feet

thick at top, and 184 feet thick at the base. In addition to this, the plan of the dam is curved on a radius of 400 feet. The reservoir formed by the dam has a capacity of 1,367,300 acre-feet, and covers 16,832 acres. It submerges a road leading from Tonto Basin to Globe, and this is replaced by providing a roadway over the top of the dam, concrete bridges across the spillways, and long approaches cut in the rock hillsides.

There are provisions for drawing water from the reservoir at three different levels. At the elevation of natural low water, a tunnel was built before beginning construction of the dam and used for diverting the river during construction. This tunnel is curved in plan, and heads 120 feet up-stream from the dam, and a grillage of reinforced concrete in the form of a tower 78 feet high protects it from driftwood. In the tunnel are placed six gates, in two sets, one designed for regular service and one for emergency use. Each gate has a clear opening of 4½ by 9 feet. They are all of the Stoney type on bronze rollers, and are operated by means of hydraulic cylinders placed in a chamber above. The gate stems pass through stuffing boxes in the floor of this chamber, which is seven feet in thickness and built of reinforced concrete. These gates were placed in the diversion tunnel in the early stages of dam construction, before the tunnel was lined. Water was discharged through these gates and the unlined tunnel for nearly two years in heads varying from zero to 100 feet, and afforded considerable regulation of irrigation water as the dam progressed, but under the higher heads the tunnel showed evidences of damage and had to be closed for repairs. The rock of the tunnel is a stratified quartzite dipping up-stream at an angle of about 30 degrees, and though hard and sound, the water had attacked the seams and crevices, and caused a large amount of damage to the natural rock walls just below the gates. It had also attacked and damaged the seats of the upper battery of gates and the piers between, and carried away a portion of the bronze roller trains. The lower set of gates and their accessories were uninjured. The tunnel was repaired with concrete and steel, and the gates again put in commission. It is not the intention to use this tunnel under heads exceeding 100 feet.

After the reservoir had been in service about four years, the sluicing tunnel again showed signs of weakness, and it was decided to place a bulkhead back of the sluice-gates and install balanced

valves therein. The valves are of the Ensign type and were installed in 1915.

About 75 feet above the river-bed is an opening 10 feet in diameter, forming a penstock to carry water under pressure from the reservoir to the power-house which adjoins the dam on the down-stream side of the left abutment. This opening is controlled by balanced needle valves.

The penstock terminates in three branches, serving three turbine water-wheels for the generation of electric power.

About 117 feet above the river, adjacent to the right abutment of the dam, are three 5-foot cast-iron pipes passing through the dam and discharging in a tunnel 9 feet in diameter, excavated in the natural rock and lined with concrete. The water follows this tunnel about 100 feet and cascades from the cliff into the canyon below the dam. The pipes and also the penstock mentioned are controlled by cylindrical balanced valves.

Each circular opening is closed by a cylindrical plug or needle, with a casing enclosing it on the up-stream side, in which it works like a piston. Water leaks between the piston ring and the cylindrical casing till the chamber is filled, when the greater area on that side of the piston acts to push the plunger to its seat with a velocity dependent upon the rate of the above-mentioned leakage. A small pipe communicates with the casing behind the piston, and by opening a valve in this pipe the pressure on that side is relieved, and the water pressure opens the plug, and closing the valve of the small pipe closes the plug.

Cement Mill.—The difficulty of access to the site presented unusual obstacles to the construction of a large dam. For example, owing to the long haul and high freights, cement in car-load lots at Globe was costing $7 per barrel, and the long mountain haul to the dam site would increase this by about $2 per barrel. Under these circumstances investigations were made to determine the feasibility of manufacturing Portland cement at the site, with the result that a mill was constructed near the site, which manufactured the cement required at about one-third the above prices.

The cement was manufactured from a mixture of limestone and clay which were found of unusual purity. The limestone occurred in a thick ledge, sloping upward from the mill site. The clay was hauled in small cars 1¼ miles. The limestone was crushed in a No. 4 gyratory crusher, which delivered the crushed

rock to a 30-foot dryer, in which wood was used. The clay was crushed in a rotary crusher which delivered it to a 40-foot dryer. The crushed and dried rock was elevated to a ball mill

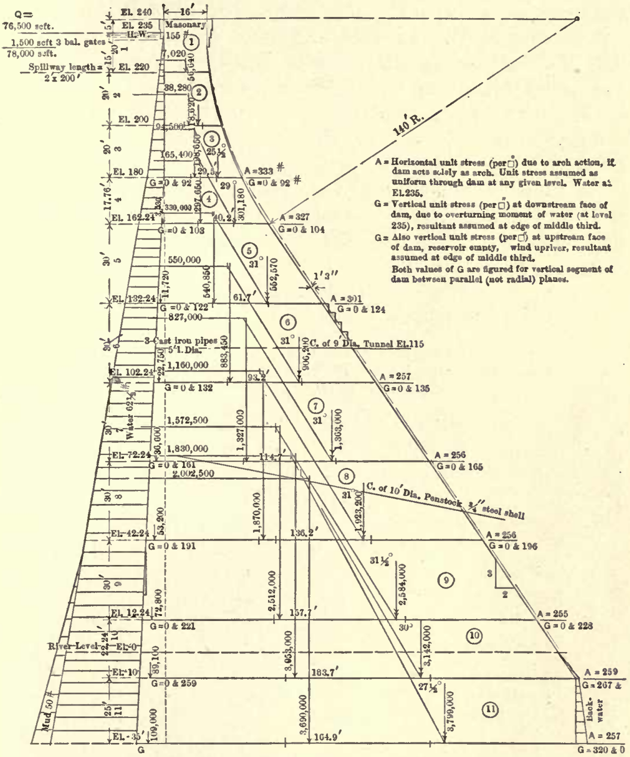


FIG. 2.—Analysis of Roosevelt Dam.

and the clay to an emery mill. After passing these pulverizers, the materials were carefully weighed in the proper proportions and ground together in a tube or pebble mill 5 feet in diameter and 22 feet long. The mixture was then burned in two rotary kilns, 70 feet in length. The fuel used was crude oil from California, of which an average of 11 gallons was used to each barrel

of cement. The clinker from the rotary kilns was delivered to a rotary cooler, and the draft of air used for cooling and becoming hot in the process was turned through the blower which supplied the hot blast of air to the kilns and dryers. The cooled clinker was passed through a ball mill, and finally finished in a tube mill. The mill was first operated at part capacity in February, 1906, and though everything was satisfactory at first, the output of the finishing tube mill gradually declined until in May its capacity was only about one-half its output in February. Experiment showed this to be due to the high temperature of the air and of the mill, and the remedy was applied by covering the tube with burlap and keeping this saturated with water from sprinkling pipes, which kept the mill cool and increased the capacity to its normal rating.

In all, 338,452 barrels of Portland cement were manufactured at this mill at the following costs:

Expense of Operation and Maintenance, Roosevelt Cement Plant, May, 1905, to July, 1910, Inclusive, 338,452 Barrels

	Total Cost	Unit Cost
Superintendence	$14,430.75	.04260
Chemist and assistants	11,389.71	.03360
Foremen	15,616.12	.04610
Labor, hoist engineer	3,338.32	.00982
" clinker burners	14,186.95	.04188
" millers	18,622.56	.05492
" operators, unskilled	31,087.94	.09165
" clay millers	6,075.01	.01792
" handling clinkers	16,884.05	.04980
" handling wood	780.25	.00231
" oilers	9,041.86	.02671
" packing cement	9,877.44	.02918
" hauling clay	39,383.68	.11630
" maintenance	35,561.32	.10501
" miscellaneous	1,988.72	.00586
Material, limestone	52,499.05	.15500
" clay	14,046.24	.04143
" wood	18,917.85	.05580
" fuel oil	360,771.97	1.06600
" maintenance	44,817.21	.13245
Supplies	11,531.71	.03401
" laboratory	1,748.09	.00513
Power	95,091.72	.28100
Depreciation of plant	233,803.09	.68950
Indemnity claim	2,050.75	.00602
	$1,063,542.36	$3.14000

Cost of Cement Plant, $249,447.92 (less salvage, $233,803.09).

This cost would have been much less had the mill been operated always at full capacity, but owing to the slow progress of the contract work and frequent interruptions thereto, the mill was often either running half capacity or closed down.

Manufacture of Sand.—Sand in the vicinity of the dam site was very scarce and badly mixed with adobe mud, and it was necessary to manufacture the quantity of sand necessary for the work. The material used for this purpose at first was a hard dolomite that occurs near the site. It was found, however, that it was deficient in finer particles and also had a tendency to crush into sharp flat flakes. These defects were remedied by grinding sandstone with the dolomite, and the mixture produced good results. The sand costs were as follows:

Cost of Sand Manufacturing
87,810 Cubic Yards

	Amount	Unit Cost
Labor, operation	$18,693.22	.213
Labor, repairs	4,609.45	.052
Material for repairs	6,578.25	.076
Supplies for operation	4,224.84	.048
Power	4,200.17	.048
Depreciation of plant	29,717.52	.338
Quarry expense	70,430.52	.802
	$138,453.97	$1.577

Cost of plant less salvage, $29,717.52.

In the foundation of the various mills and buildings, large quantities of lime and brick were used, both of which were burned near the dam site. About 3,000,000 board-feet of lumber were required for concrete forms, buildings, and other temporary works, and this was manufactured for these purposes in the neighboring mountains.

The scarcity of fuel and the expense of bringing it in made it necessary to develop water-power at the site, which was done by diverting the river above the reservoir into a canal of 250 second-feet capacity and dropping the water below the dam through wheels under a head of 226 feet.

Construction of Roosevelt Dam.—The Roosevelt Dam was constructed under contract by the J. M. O'Rourke Construction Com-

pany, the United States undertaking to furnish the required cement and sand free and electric power at ½ cent per kilowatt hour.

The canyon was spanned by two cableways, each 1,200 feet long and 2¼ inches in diameter, about 85 feet apart. They commanded the foundation excavation, the masonry of the dam, and the excavation for the spillways around the ends of the dam, from which rock for the rubble masonry was obtained. Five stiff-leg derricks were provided for handling materials on the dam, and ten derricks were used in the quarries. The machinery was operated by direct current at 500 volts from a motor-generator set actuated by alternating current from the Government water-power plant.

The mixing plant was located on the left bank, 125 feet above the dam. The cement was delivered from the mill, 1,700 feet distant, by means of an aerial cable tramway, which also delivered the sand to the mixing plant. A number 7 crusher prepared the rock for the mixer, which mixed about 1¼ yards of concrete per batch.

The excavation was accomplished mainly by two hydraulic excavators working under a pressure of about 220 feet from the power canal, throwing the material into a flume and washing it down-stream. All of the pumping done was performed by hydraulic jet-pumps, working upon the same principle. This was a very cheap and convenient mode of pumping, and as the work was frequently overwhelmed by floods, it was employed extensively. Owing to frequent and long-continued floods and other delays, the masonry was not completed to the original river-bed until over three years after the signature of contract.

The body of the dam was built of random rubble bedded in mortar and with vertical joints filled with concrete. The faces are of coursed rubble similarly laid. The masonry was composed of large stone, 40 per cent; spalls, 10 per cent; concrete, 35 per cent; and mortar, 15 per cent. Each cubic yard on an average required .76 barrel of cement. The dam and wing walls contain about 342,000 cubic yards of masonry, and were built at an average rate of 13.2 cubic yards per derrick-hour of actual work, the maximum rate reaching at times over 20 cubic yards per derrick-hour.

FIG. 3.—Rock Cut on Mountain Road, Salt River, Arizona.

Cost of Construction of Roosevelt Dam

Contract with J. M. O'Rourke & Co., Signed April 8, 1905

Excavation, Class 1, 73,135 cu. yds. at $1.75		$ 127,986.25
" Class 2, 6,137 " " 5.00		30,685.00
" Class 3, 222,268 " " 1.50		333,402.00
Dam Masonry, 333,306 " " 3.15		1,049,913.90
Coping masonry, 444.5 " " 20.00		8,890.00
Wing wall masonry 8,047.3 " " 4.75		38,224.67
Concrete in bridge piers, 1,172 " " 6.00		7,032.00
Masonry bridges, 2 at $7,500		15,000.00
Overhaul, 426,573.6 cu. yds. at 15 cents		63,986.04
Changes after work commenced		38,262.00
		$1,713,381.86
Items not covered by contract:		
Pilasters		8,913.30
Capstones		2,390.50
Gate and tool houses		14,340.01
Sprinkling system		1,063.97
Lighting system		4,658.18
Repairs to toe of dam		15,579.64
Loss on power		91,313.72
Bridge railings		1,809.02
Laboratory expense		1,921.53
Miscellaneous labor and materials		31,211.86
Cement, 305,213 barrels		787,451.10
Sand		136,612.09
Engineering and superintendence		49,210.72
Inspectors		43,426.77
Camp maintenance		64,891.31
		$2,968,175.58
Proportion General Expense		221,829.63
Total Cost		$3,190,005.21

Power Development.—The power development at the dam consists of two separate classes of units, one deriving water from the power canal and the other using the water from reservoir as it is discharged for irrigation purposes.

Water may be drawn from the reservoir by three passages. One, the sluicing tunnel, is built at an elevation so that the reservoir may be entirely emptied. The flow through the tunnel is regulated by two sets of gates, three gates in each set. These gates, with the operating mechanism, weigh about 800,000 pounds, have a net

opening of 5 by 10 feet, and are constructed for a pressure of 100 pounds to the square inch. The second passage for water from the reservoir passes through the dam and consists of a riveted steel penstock 10 feet in diameter, and the elevation of the penstock intake is 70 feet above the bottom of the reservoir. This penstock is equipped with a special emergency valve 10 feet in diameter, and is connected with the water-wheels of the permanent power-house. The third passage of water from the reservoir is a tunnel some 260 feet in length through the rock on the other side of the river from the main sluicing tunnel. Water is taken through the dam into this tunnel by three lines of cast-iron pipes, each 5 feet in diameter, having an elevation at the intake end of 150 feet. The control of the water is effected by means of a 5-foot balanced valve located at the intake end of each pipe, described on page 10.

In order to have power for construction operations and for lighting, a power canal was built to serve the first turbine and generator unit. The dam and intake for this canal are located on Salt River above the highest contour of the reservoir, about 19 miles from Roosevelt. The dam consists of an overflow weir, built of boulders and concrete. The crest is 400 feet in length, and is about 7 feet above the low-water level of the river. The power canal sweeps through the open country, following the course of the river, and is for the greatest part an open cut cement-lined ditch, although in some places it takes the form of a tunnel and also a covered reinforced cement flume.

The temporary power-plant was located in a cave in the vertical cliff immediately below the dam at Roosevelt. This sheltered location gave protection to the apparatus during blasting, and when the permanent plant was installed the niche or cave was utilized for the housing of switching and controlling apparatus. The temporary plant consisted of a 1,300 horse-power water turbine connected to a 950-kilowatt generator.

The permanent power-plant is located at the foot of the dam and is built into the vertical cliff. The building is on a rock foundation, and the draft tubes and tail-races are built in rock. Two penstocks enter the building, one from the power canal and the other through the dam. The water from the power canal is brought to three of the units through an inclined tunnel lined half-way down with concrete only; the balance of the way the

concrete is lined with steel plate. A 7-foot penstock extends from the lower end of the tunnel connecting with the three 1,800 horse-power vertical water turbines driving 950-kilowatt generators. The 10-foot penstock through the dam will ultimately serve three units, one of these 2,000 kilowatts and two of 1,200 kilowatts capacity. The generators supply twenty-five cycle, three-phase current, at 2,300 volts. The units served by the power canal will have a constant static head of 226 feet, while the units served by the penstock through the dam will operate under a variable head, dependent upon the height of water in the reservoir. They are designated to give maximum efficiency at a head of 160 feet, and they will be controlled to operate at heads varying from 90 to 220 feet. S. Morgan Smith water-wheels drive the two 100-kilowatt exciter generators, and two Pelton wheels drive pressure pumps for the governor oil system. Lombard governors are attached to the large units and the two small exciter wheels are equipped with Woodward governors.

In the niche where the temporary power-plant had been installed, back of the main power-house, the 2,300 volt bus-bars and switches are located. There is a complete double bus-bar switchboard, with selector switches for both generators and transformers. The generator bus-bars are carried upon insulators supported upon brackets overhead, and the lead-covered cables from the generators to the bus-bars are equipped with station terminals at both ends. There are two sections of switch cells, each bank being 24 feet long. The switches are mounted upon slate panels, housed in concrete compartments, 16 inches wide. The concrete barriers between the cells are 4 inches thick. The separate circuits are protected by disconnecting switches on either side of the solenoid-operated oil switches and all outgoing cable is carried to a wire tower upon the roof of the power-house. On a gallery upon the level of the switch-room, and overhanging the main power-plant, are placed all the controlling apparatus. All remote-control apparatus for handling the various valves controlling the sluicing and water intake is controlled from this gallery.

The transformers and high-tension switches are located in a separate building about 600 feet from the power-plant. The copper cables are carried in a long span from the wire tower to the transformer house, which is a three-story building. The

first floor contains the transformers and accessory repair and maintenance supplies, the second floor the double bus-bar and disconnecting switches, and the third floor the solenoid-operated oil switches and outgoing line accessories. There are six groups of water-cooled transformers, transforming from 2,300 volts to 45,000 volts. These transformers have a nominal capacity of 350 kilovolt-amperes, and were built according to the specifications of the Reclamation Service.

The first floor of the transformer house is served by a large repair pit, and any transformer may be wheeled to the pits. The transformers rest upon large casters, are in fire-proof compartments, and each three-phase group is isolated by concrete barrier walls. Switches and bus-bars are inclosed in concrete cells, the busses being carried on line insulators. The incoming 2,300 volt lines are equipped with multigap lightning arresters. The two 45,000-volt lines are handled by motor-operated oil-switches, passing from these to the choke-coils, thence to 24-inch vitrified tile pipes direct to the first tower of the transmission line. The outgoing lines are equipped with aluminum cell lightning arresters.

The transmission line consists of six 83,000 circular mill, 6-strand, hemp core, hard-drawn copper wires supported upon 14-inch insulators passing a test of 165,000 volts dry. The line is supported on steel towers with the lowest wire at a limiting distance of 30 feet from the lowest wire to the ground in the valley and 20 feet in the mountains. The average span is 360 feet in the mountains on account of the rough country, and 400 feet in the valley. The line is 65 miles long, reaching to Phœnix. Forty miles from the power-house a branch line is tapped off from a four-way switching station near the town of Mesa, running south for 20 miles and terminating in the substation at the Pima Indian Reservation. There is also about 10 miles south of the main line another substation for general irrigation pumping. In addition to supplying power for irrigation purposes, the main transmission line delivers power to the Phœnix substation of the Pacific Gas & Electric Company, and to several small industries.

The wires are spaced at the angles of a 4-foot equilateral triangle. Both circuits are carried on the same towers. One circuit is transposed one-third of a spiral every 2 miles and the other every 4 miles. At four points along the line the towers are fitted up so that by taking out a clamp the line may be

opened for testing and working. Across the mountains and desert the wires are carried on galvanized-steel towers. In the irrigated region steel poles are used.

The towers in the mountain region are mounted on concrete bases or anchored in the solid rock. There are 418 towers, and 67 are double-braced and the balance single-braced. In the section from Goldfield to Highland Canal there are 192 towers set on anchor plates, about 2 feet in diameter, buried from 4 to 5 feet in the ground. On the towers there are four wires on the upper cross-arms and two on the lower. The cross-arms are made of channel iron. The towers on straightway sections of the line are single-braced. On the steel poles there are four wires on the lower cross-arm and two on the upper. The cross-arms are made of U-bar section similar to the ribs of the pole and have diagonal braces and vertical struts between the two cross-arms to brace them.

At the beginning of service it was found that a number of short-circuits were caused at certain points by large hawks sitting on the towers and touching the wires with their wings or bodies. A guard was therefore designed, consisting of a cast-iron cluster clamped to the tower and holding pointed rods of $^5/_{16}$-inch birch dowels spread so as to prevent the birds alighting. Placing these improved the service somewhat, but much trouble was still encountered.

After considering the development of transmission practice in other regions, it was finally decided to rebuild the valley portion of the transmission line for the purpose of overcoming these difficulties.

Alternate towers were eliminated, and those remaining were built 12 feet higher, making a clearance of 42 feet at towers. The span through the valley was thus lengthened to 800 feet. Suspended insulators were substituted for the original insulators, removing the favorite lighting-place for birds. This reconstruction has perfectly accomplished its purpose of eliminating almost entirely the interruption through open country.

The main switching station near Mesa is a concrete building 52 feet long, 30 feet wide, and 26 feet high. The branch line running south to the Gila River Indian Reservation leaves the main line at this point. This building contains the necessary switches to control the circuits on either side of the

main system or the branch. The station is protected by aluminum cell lightning arresters. The lines are deadened at the station entrances on disc type insulators and pass through open tile bushings to a set of four switches.

About 7½ miles south of Mesa, and 1 mile west of the branch line, is located the Chandler substation, which is a building of reinforced concrete, 54 feet long by 23 feet wide and 23 feet high. It contains three transformers from 45,000 to 10,000 volts. A secondary distributing line, which totals about 10 miles in length, starts from this station and will distribute energy to pumping stations located in the area above mentioned. The Sacaton substation is located about 20 miles south of the switching station on an area that will be irrigated by pumping. It is similar in construction to substation No. 1, and contains three transformers stepping down from 45,000 to 10,000 volts. A secondary distributing line, about 10 miles in length, starts from substation No. 2 for the distribution of energy at 10,000 volts to eleven pumping stations.

The pump houses are built of concrete and are directly over the wells. The equipment consists of current transformers operating overload relays, 10,000-volt automatic oil switches, oil-insulated air-cooled transformers, and the single-panel switchboard. The vertical induction motor operates on 220 volts, starting taps being taken from the secondary of the transformer for starting the motors at half voltage. Pumps and motors are mounted on vertical shafts. The mechanism of the motor, pump and frame is mounted on I-beams, built into the concrete well-casing. The motor can be unbolted and lifted out, and the frame and pump lifted out for examination. The pump-house is served with an overhead I-beam, equipped with differential pulley for lifting the heavy mechanism.

The wells are sunk in single batteries and in drifts of two and three, the pump suction going to a common manifold where there is more than one well in the battery. The wells consist of a 16-inch California well-casing driven to a depth of 200 feet, a large portion of this depth consisting of coarse gravel. Around this is sunk a concrete caisson, 9 feet in diameter, to a depth of from 45 to 55 feet.

GRANITE REEF DIVERSION DAM

When water required for irrigation is liberated from the Roosevelt Reservoir it flows down Salt River about 45 miles to

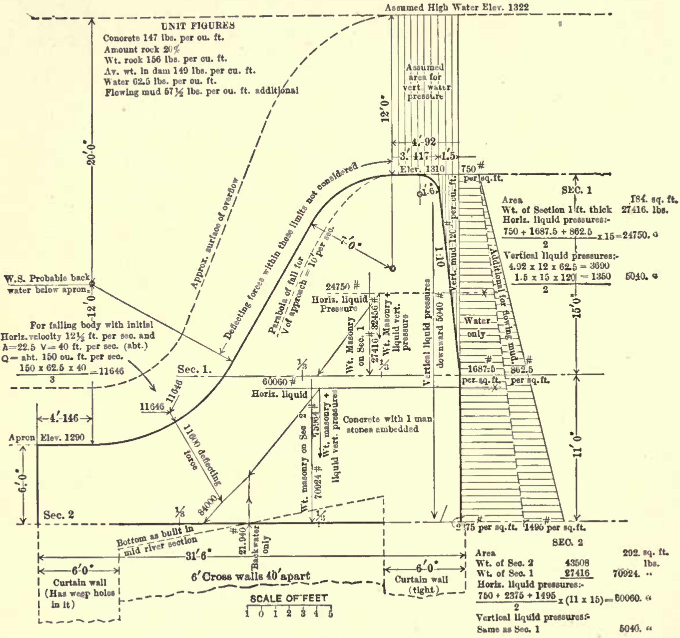


FIG. 4.—Analysis of Granite Reef Dam, Salt River, Arizona.

the Granite Reef diversion dam, 2 miles below the mouth of the Rio Verde, its main tributary.

The diversion dam is of the gravity ogee type, is built of rubble concrete, and is 38 feet high and 1,000 feet long. At each end of the dam is an intake structure, canal-heading and sluiceway. The north side canal has a capacity of 2,000 cubic feet per second, provided with eighteen regulator-gates and four sluicegates. The south side canal has a capacity of about 1,200 cubic

feet per second, regulated by nine head-gates, and has two sluice-gates. The plan of this structure is shown in drawing, Plate IV.

Salt River, like most Southwestern streams, carries a great load of sediment, especially in times of flood. This load varies from coarse sand to impalpable silt. Where the river water is diverted into canals in time of flood it carries with it a large amount of sand and silt, the coarsest of which is deposited in the canals and entails large expenditures for removal in order to keep the canals open. It is important, therefore, to prevent, so far as possible, the heavier and coarser particles from entering the canal. The finer and lighter portions can be carried through the canals and laterals and applied to the land with the irrigation water, where they are valuable for fertilizing purposes. A combined sluiceway and settling basin are provided directly in front of the regulator-gates to take out the coarser material. This basin is limited on the land side by the regulator-gates and on the opposite side by a training wall of concrete parallel to the regulator-gates and to the axis of the river. The bottom of the basin, or sluice, is built on a slope 1½ per cent down-stream and is 3 to 4 feet below the sills of the regulator-gates. This floor is continuous with the sill of the sluice-gates, which are 8 feet below the crest of the dam.

As the water approaches the canal-gates its velocity is checked and it is required to change its direction and flow at right angles to the course of the river. This causes it to drop the heavier sediment in the deep sluicing channel, which soon fills that channel. When this occurs the sluice-gates are opened, and the rushing waters under the large available head rapidly cut away the sand in the channel, and a few minutes is sufficient to restore a basin for the settlement of sand. At times of low water, when there is no surplus water available for sluicing, the stream usually runs more nearly clear and sluicing is less necessary. At such times, however, a small quantity of sand may be slowly moving along the bottom and necessitate occasional sluicing. The water thus used need not all be wasted, however, as there are other diversions below.

Construction of Granite Reef Dam.—This work was begun in the fall of 1906, and was completed to a point so that water was diverted into the Arizona Canal, June 13, 1908. The work was greatly delayed, hampered, and made more expensive by the

delay for more than a year on various pretexts in the delivery of a cableway and appurtenances for use on this work. This prevented entirely or partially the economical use of various equipment purchased and installed, but which could not be used without the cableway.

A transmission line was built from the hydro-electric plant of the Pacific Gas & Electric Company, which furnished electric power for construction purposes. An electric railway was constructed to a quarry opened on the south side of the river about one-half mile above the dam, which furnished all the rock used in the dam, except such boulders as could be readily secured from the river-bed.

Cement was used mainly from the Government mill at Roosevelt, from which point the haulage was ten dollars per ton. Cement from Iola, Kansas, cost $3.53 per barrel f.o.b. Mesa, and $0.92 per barrel haulage from Mesa to Granite Reef, making a total cost per barrel of $4.45, which was greater than the cost of the Government cement.

The river-bed at the dam site consisted of sand, gravel, and boulders, underlaid with coarse-grained gray granite rock for about two-thirds the length of the dam, but directly under the main channel of the river the rock was too deep for foundation purpose, and this portion of the dam was founded on a bed of compact gravel.

The dam has a clear overflow length of 1,000 feet between the sluiceways at each end. Some additional spillway is available over or through the sluice-gates, at each end of the dam.

The height of the main body of the dam is 26 feet and its crest is about 20 feet above low water. The base of the maximum cross-section is 36 feet wide, and curtain walls at the toe and heel of foundations are carried to varying depths into the gravel. An apron 18 inches thick, in blocks 10 feet square, is carried down-stream from the toe for a distance of 75 feet and terminates in a curtain wall. The area of cross-section of the dam exclusive of apron and curtain wall is 476 square feet. (See Fig. 4.)

No reinforcement was used except to bond the masonry with the rock and to connect joints in the concrete work.

The concrete was mostly made of the natural gravel and sand into which boulders and broken rock were crowded.

There are eighteen intake- or regulator-gates, the sills of which

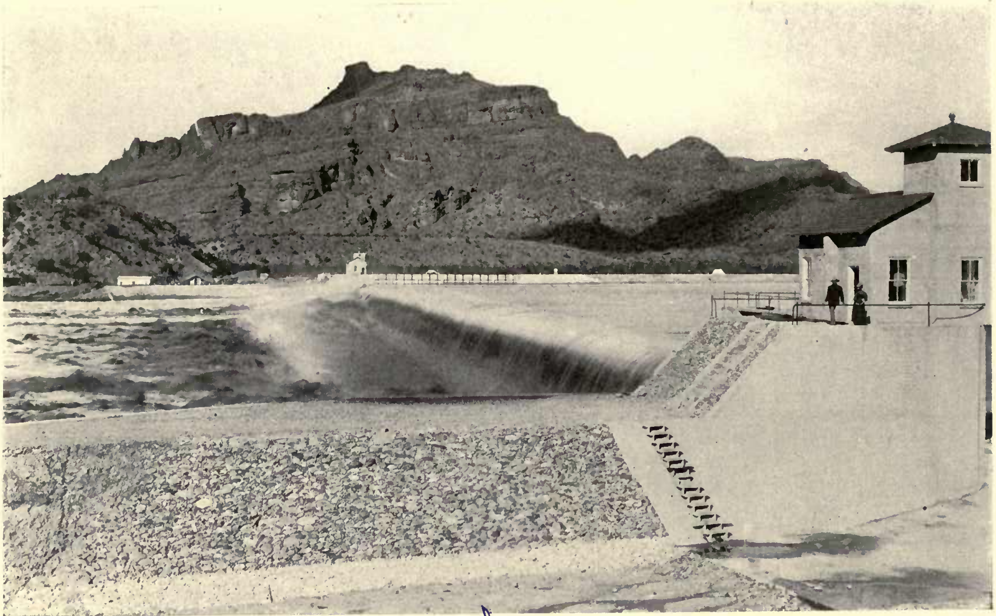


FIG. 5.—Granite Reef Dam in Flood, looking north. Salt River, Arizona.

are 4 feet lower than the crest of the dam and 4 feet above the upper end of that floor. The lower end of the sluiceway is closed by four sluice-gates, 9 feet high by 15 feet wide. The sluice-gates are operated by chains and wire ropes passing around pulleys and through a tunnel under the gate sills around a drum to a hydraulic piston moving in a cylinder of 28 inches diameter. They are operated by a gasoline engine.

Each sluice-gate consists of a cast-iron shell filled with concrete, and weighs about 30,000 pounds.

The regulator-gates are likewise of cast iron, and they close upon oaken sills. They are curved toward the water, and have a buoyance greater than their weight, to assist in opening. They are operated by the gasoline engine, the shaft of which carries two gears on the sleeves of a duplex friction clutch. The gears transfer their motion to a counter-shaft connected with the gears of the gate stands.

CANAL SYSTEMS

On the Salt River Project are two canal systems, one on each side of the river, heading at the Granite Reef Dam. The one on the north side, called the Arizona Canal, has a capacity of 2,000 cubic feet per second, and serves about 127,000 acres of land. The South Side Canal has at its head a capacity of 1,200 cubic feet per second and is capable of serving about 80,000 acres. Another diversion point occurs about 24 miles below Granite Reef Dam, called the Joint Head, where a low concrete dam diverts water into the joint head of the old Salt and Maricopa Canals. This diversion utilizes a considerable amount of return seepage water flowing into the river from the irrigated region about Mesa and Tempe. The capacity of this canal is about 200 cubic feet per second. The present water supply is estimated to be sufficient for about 200,000 acres, but can be increased by additional wells, or by providing a storage reservoir in the Rio Verde.

On the Arizona Canal, about 12 miles below its head, a branch called the new Crosscut Canal runs southward along a ridge, and drops 115 feet through impulse water-wheels, and develops 6,430 horse-power; the water, after leaving the plant, passing into the Grand Canal, is carried down the valley for irrigation. Further down the Arizona Canal is a drop of 18 feet, where 1,130 horse-power is developed. The South Canal, about 12 miles

Granite Reef Dam

Feature	Unit	Quantity	Cost to the United States	
			Unit	Total
Borings, principally sand gravel and boulders	L. Ft.	2530	2.60	$6,589.25
South Levee				
Embankment—exc.	C. Y.	1690.9	.31	3,472.27
fill	C. Y.	9458		
18″ dry rock paving	S. Q.	3106.8	5.56	17,273.17
North Levee				
Embankment—exc.	C. Y.	8544.2	.37	14,957.68
fill	C. Y.	31360.7		
18″ dry rock paving	S. Q.	5813.3	2.58	15,007.16
Concrete	C. Y.	173.6	6.81	1,182.93
South End Structures				
Excavation—earth	C. Y.	10924.5		
rock	....	1508.4	1.85	26,401.47
earth fill	....	1831.8		
Concrete	C. Y.	5685.6	9.73	55,314.36
Gates and machinery	Lbs.	....	......	29,236.55
North End Structure				
Excavation—earth	C. Y.	18876.5		
rock	....	743.3	1.14	34,766.75
earth fill	....	10917.6		
Concrete	C. Y.	8071.3	10.22	82,501.87
Gates and machinery	Lbs.	....	......	51,628.33
Main Dam and Apron				
Excavation				
Apron—earth	C. Y.	10177.5		
Dam—earth	....	14226.5	2.49	61,342.26
Dam—rock	C. Y.	192.5		
Concrete (boulder)	C. Y.	17893.5	7.60	135,711.53
Apron and curtain walls. Conc. (boulder)	C. Y.	3378	10.24	34,573.94
Rock fill	C. Y.	4040.5	.75	3,030.38
Betterments				
Apron	....	....	......	8,171.41
Sluiceways and levee	....	....	......	3,020.28
Prop. of cost of Ariz. Canal heading	....	....	......	30,854.76
Operator's Residence				
Grading	....	....	......	3,236.53
Fence	....	....	......	2,006.26
Water supply	....	....	......	1,299.31
Roads	....	....	......	68.91
Corral shed	....	....	......	902.94
Miscellaneous expense not classified	....	....	......	233.74
Lighting and pumping plant	....	....	......	2,161.34
Installing electric machine for opening gates	....	....	......	2,112.22
Total	....	....	......	$627,057.60

below its head, drops the major portion of its water into the Consolidated Canal, with a fall of 26 feet, and develops 2,140 horse-power. This, with the 12,000 horse-power developed at Roosevelt, makes a total installation of 21,700 horse-power, which is used for pumping underground waters and for commercial purposes.

The average amount of power available is, however, far less than the above figures of total installation. The primary use of the water is for irrigation, and although this is carried on every month in the year, except when local rains render it temporarily unnecessary, the Rio Verde joins the Salt River below the storage reservoir, and whenever it is in flood, which frequently happens in winter, it is impossible to draw water from the Roosevelt Reservoir without wasting it, and this the irrigation requirement will not admit. The Roosevelt plant is, therefore, unavailable or partially so during much of the winter, when the need for water in the valley is least.

This fluctuating power supply is, however, fairly well adapted to the pumping requirements. The wells for tapping the underground waters are scattered through the Valley among lands served from the gravity canals, and into these canals the well water is pumped. When no water is being drawn from the reservoir it is because the Verde flood waters are sufficient for irrigation needs, and at such times the well water is not needed. When the floods subside, and more water is needed, a part is drawn from the reservoir, and the power generated thereby is used to pump the rest of the water needed from the wells.

This condition, however, represents only a small part of the great fluctuation of the power supply. The crop needs for water are so much less in winter than in summer, and are so much more fully served by the Rio Verde and by the winter rains, that far more power is available in summer than in winter, not only at the reservoir, but in the canals which are steadily used to nearly their full capacity in midsummer, and the Valley power plants can then run to near their capacity, while in winter the water thus available for power is far less. The power steadily available, and therefore adapted for general commercial uses, is limited to that which can be generated at the canal drops during the minimum winter consumption of irrigation water. To make the large summer power available, therefore, it is necessary to supple-

Fig. 6.—Concrete Flume on Crosscut Power Canal. Salt River Project.

ment it with steam, and an advantageous contract has been made to accomplish this end. The great expense of fuel in the neighboring mining regions renders power very valuable there, even when intermittent. Arrangements have been made by which the mining interests provide full steam equipment to furnish power when necessary, and take all the surplus power from the project up to a maximum of 800 kilowatts whenever any surplus is available, paying for the current thus consumed ¾ cents per kilowatt hour.

The character of the installation at the three Valley power plants is shown in the table below:

	South Consolidated	Arizona Falls	Crosscut
Water-wheels	2 twin horizon.	2 twin horizon.	6 impulse
Capacity, each	1,400 H.P.	725 H.P.	1,000 H.P.
Speed	166 R.P.M.	150 R.P.M.	94 R.P.M.
Head static	26 to 28 ft.	18 to 20 ft.	116 ft.
Diameter	48 inches	45 inches	
Maximum efficiency	78%	80%	75%
Weight	81,000 lbs.	60,000 lbs.	
Factory price	$6,150	$5,750	
Governors	10″ x 16″	7½″ x 16″	Deflection
Generators	3 ph., 25 cyc.	3 ph., 25 cycle	6, 3 ph.
Voltage	2,300 volts	11,000 volts	11,000 volts
Capacity, each	1,000 KVA	530 KVA	875 KVA
2 hr. overload capac.	1,250 KVA	663 KVA	1,094 KVA
Temperature rise	40%	40%	50%
Efficiency test	95.75%	93.5%	93.5%
Weight	62,100 lbs.	49,500 lbs.	78,000 lbs.
Transformers	7 water cooled	None	12 water cooled
Rated capacity	333 KVA	None	500 KVA
Efficiency	97.5	None	97.6
Upper voltage	40,000 volts	....	40,000 volts
Crane	15 tons	12 tons	20 tons
Span of crane	37′ 6″	39′ 6″	39′ 4″
Spillway	6 siphons	3 siphons	Weir, 344 ft.

The use of impulse wheels at the Crosscut plant was prompted by five reasons:

(*a*) The parts subject to erosion by the muddy water are reduced to a minimum and are simple and easily replaced.

(*b*) Water hammer is eliminated by the use of jet deflectors and small valves controlling the various jets. This makes it possible to use concrete penstocks and to eliminate surge chambers.

(*c*) Great flexibility and better part-load efficiency are obtained

by closing part of the nozzles on the wheel, and operating under small load with perfect jets.

(*d*) Steady irrigation flow regardless of fluctuation of power load is secured by means of jet deflectors.

(*e*) It is estimated that this plant is cheaper than a turbine plant for this location.

JOINT HEAD DIVERSION DAM

Considerable return seepage water reaches Salt River from the irrigation of the lands in the Upper Valley, especially the Mesa and Tempe regions, and this water is picked up by a diversion dam in the river about 3 miles below the town of Tempe, which serves as a heading to the Maricopa and Salt River Canals, and is called the "Joint Head." This dam is a low concrete weir of the ogee type, with a broad apron below it to prevent erosion of its toe. Its right abutment is in soft rock and the canal head-works are founded on the same. Its left abutment is a concrete structure flanked by an earthen dike reaching across the flood plain to higher ground. The dam was built by Government forces, and has the following costs:

Joint Head Diversion Dam

Earth, Excavation Part Wet, Rock All Wet, Mostly Removed by Hand Without Blasting on Account of Proximity of Gates. Two Pumps Operated During Most of Construction

Feature	Unit	Quantity	Cost to the United States		
			Unit	Total	Feature
Excavated sand, gravel, and boulders	C. Y.	10,341	.77	$7,995.78	
Exc.—decomposed granite	C. Y.	464.8	7.84	3,645.87	
Levee fill	C. Y.	3,774	.37	1,410.91	
Backfill	C. Y.	2,100	.33	699.31	
Backfill	C. Y.	390	.84	326.67	
Concrete—boulder	C. Y.	1,254.7			
reinforced	....	368.6	11.66	18,926.42	
Cobble paving—grouted	C. Y.	398	2.16		
dry	Sq. yd.	40	2.16	948.23	
Gates and machinery	Lbs.	....	.....	5,167.50	
Removing old structure	....	....	....	206.14	
Rock riprap	C. Y.	....	.....	202.10	
					$39,528.93

The distribution system of the Salt River Project is a very complete one, and is adapted to a highly developed system of rotation irrigation. Each tract of land is irrigated at intervals of about eight days, with a head of water of from 5 to 15 cubic feet per second, according to circumstances. The quantity of water delivered to each irrigator depends on the acreage he irrigates, and is measured by the length of time he uses the known head. This method of rotation secures the maximum of economy both of water and of the irrigators' time. It requires sublaterals of a capacity to carry the head used, but effects a large saving in the installation and operation of measuring devices, since it is only necessary to provide one module for each group of irrigators using a single head.

The lateral system in use prior to the advent of the Government project was generally inefficient and inadequate. The structures were of wood, largely decayed, and the laterals silted and weedy. Many of the farms were served each with a separate lateral from the main canal or main lateral, and thus two, three, four, five, or six laterals were operated parallel and side by side. This, of course, was wasteful of labor and of water. To a large extent the old systems were rebuilt. Nearly all the canals have been enlarged and concrete structures substituted for wood. An ideal distribution system is favored by the even and adequate slope of the land.

In general, each section of irrigated land has a waste ditch at its lowest corner which carries the surplus irrigation water to a lateral from which it can be again applied in irrigation.

Some of the lower lands of the Valley have been injured by the rise of ground water and alkali, and such lands have generally been excluded from the Government project. It is hoped that the high degree of economy which is being attained in this Valley by the rotation system and the universal charge for water by the quantity used will largely prevent over-irrigation so common in other regions. No material spread of seepage has been observed since the reservoir was brought into service, and no drainage works have been undertaken nor planned.

The construction of the Salt River Project was in charge of Louis C. Hill from the first, with Geo. Y. Wisner and W. H. Sanders as consulting engineers. The power and pumping equipment and the balanced valves were all designed by O. H. Ensign.

WATER DELIVERY

The lateral system on the Salt River Project was so designed as to deliver to each quarter section of land a head of 10 cubic feet of water per second. For many years the custom was followed of delivering such head for a period of 24 hours in every eight-day period, *i.e.*, water delivered 24 hours and seven days without water.

This system was used in the main during the years when water was delivered on a flat-rate basis, the charge at that time being generally $1.60 per acre per year.

In 1912 the basis of charge was changed from the flat rate to payment for quantity of water used in order to encourage economy, and the rigid rotation system was abandoned. Water is now being delivered in large heads, but instead of a regular rotation deliveries are being made in accordance with requests which are required to be presented 24 hours or more in advance of the need. From these requests, rotation schedules are made up from day to day as far in advance as possible, and in most cases it is feasible to deliver water in accordance with the requests made.

In extremely hot weather during the maximum demand for water, these requests frequently conflict to such an extent as to make their fulfillment impossible, and in those cases the irrigators are notified that the water will be delivered on a rotation system.

When a lateral is placed on a strictly rotation basis, it is the custom to begin at the lower end and work up to the head of the lateral, giving to every water-user a head of from 7½ to 10 cubic feet per second for from 24 to 36 hours for each quarter section of land. Generally when the demand for water at any particular time has been greater than the capacity of the canal to supply, it is necessary only to advise the farmer that the canal would be placed on a regular rotation basis and the demand immediately decreases, the farmer being willing to wait a few days for water rather than have the canal placed on regular rotation.

The delivery head, however, is the same for both plans of delivery, and the method followed on the Salt River Project is the most economical, both of time and of water, which seems to be practicable. However, handling water under such large heads requires larger sublaterals, larger farm ditches, better preparation, and greater skill to irrigate than when water is delivered in smaller heads.

CHAPTER III

THE YUMA PROJECT

DESCRIPTION

The Colorado River is formed by the junction of the Green and the Grand Rivers, which unite in southeastern Utah. From that point for a distance of more than 1,000 miles the Colorado flows through the most profound, extensive, and precipitous canyons on earth. Through these canyons it falls a vertical distance of nearly 4,000 feet, and receives many important tributaries of still greater slope in precipitous gorges. It emerges from its canyons as the boundary-line between Arizona and Nevada, heavily laden with sediment gathered from the rocks and hills on the way. With this sediment the river has built an immense delta at its mouth in the Gulf of California. It has forced this delta entirely across the Gulf, and isolated the head of the Gulf, forming an inland depression in Southern California, known as the Salton Sea. The valleys of the Lower Colorado are typically those of a silt-laden stream overflowing its banks annually in the season of high water, and depositing a portion of its load of sediment on the adjacent valley. In order to cultivate these valleys successfully, it is necessary to protect them with levees.

The Yuma Project provides for the diversion of the Colorado River about 10 miles above Yuma into two canal systems. One on the California side of the River, to irrigate lands on the Yuma Indian Reservation. and by crossing under the Colorado River near Yuma to irrigate lands on the Arizona side below Yuma. The other canal system heading on the Arizona side, watering lands east of the Colorado and north of the Gila River.

It is also expected ultimately to pump water from the gravity canals to irrigate land on the mesa south of Yuma, and a small tract above the canal in the Gila Valley.

LAGUNA DAM

The diversion dam is located about 12 miles above Yuma at the most southerly site on the Colorado River, where it is feasible to locate a dam with rock abutments at both ends.

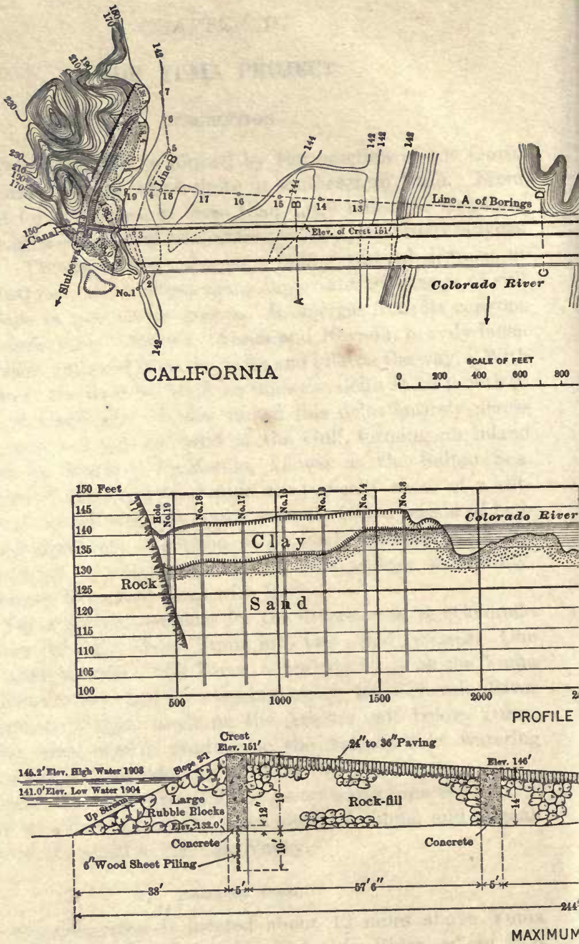
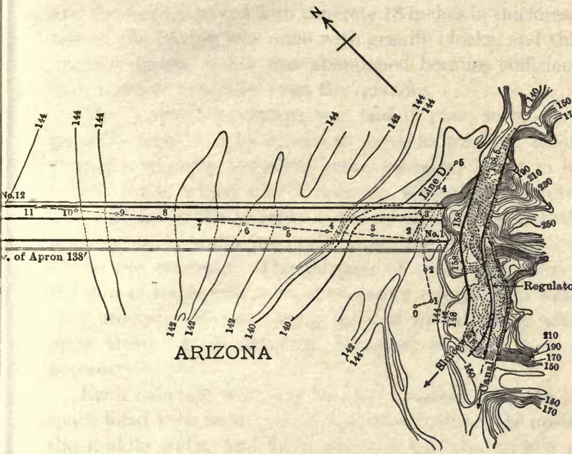
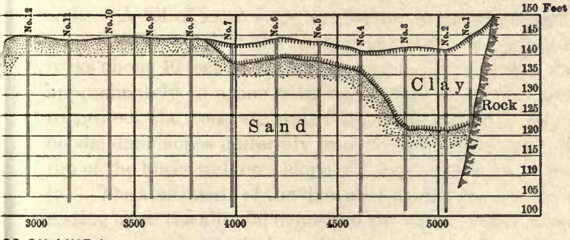
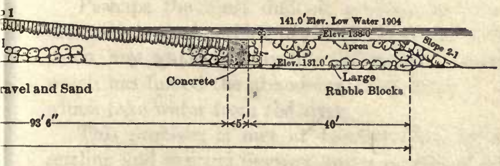


FIG. 7.—Plan and Sectio





GS ON LINE A



ON C-D

una Dam, Colorado River.

The dam consists mainly of three parallel concrete walls across the valley with intervals between the walls filled with loose rock and the surface paved with concrete 18 inches in thickness. A portion of the paving was done with granite blocks, and this was the original design, which was abandoned because sufficient suitable rock was not available from the quarries.

The concrete pavement was laid in place in blocks $10' \times 15'$ partially separated by cracks to serve as weepers, formed by inserting a specially prepared board on edge, 7 feet in length and 1 inch thick, which was withdrawn when the concrete had set. The surface of the pavement was roughened by inserting in the concrete, at irregular intervals, sound rock projecting a few inches above the concrete. The purpose of these rocks was to retard the flow of water and prevent excessive velocities, in which respect they are very efficient, being assisted by driftwood which lodges upon them. It is doubtful, however, whether they are really necessary.

Each concrete wall is 5 feet in thickness, and the interval of space filled with loose rock is 57½ feet between the up-stream and the middle walls, and 93½ feet between the middle and lower walls. A fill of loose rock was placed above the upper wall on a 2 to 1 slope. Below the lower wall, a blanket or apron of large rocks about 40 feet wide was dumped on the river-bed and brought approximately to a line with the pavement on the dam, in order to protect the concrete wall from undercutting. The pavement on the dam slopes uniformly from the top of the upper wall to the top of the lower wall on a slope of 1 foot vertical to 12 feet horizontal. The abutments of the dam are founded on rock, the remainder resting upon the alluvial deposit of the valley, which was excavated to an average depth of about 12 feet, except in the river-bed, where the excavation was very slight.

Perhaps the most difficult problem in connection with this diversion is the handling of the silt with which the river is heavily laden, and which quickly fills the canals if permitted, a difficulty which has forced the abandonment of most of the private canals which take water from the river.

This problem is met at Laguna Dam by a combination of settling and sluicing devices, and a process of admitting only the surface of the water into the canals. A settling basin is provided at the head of each canal, where the flowing water is checked to

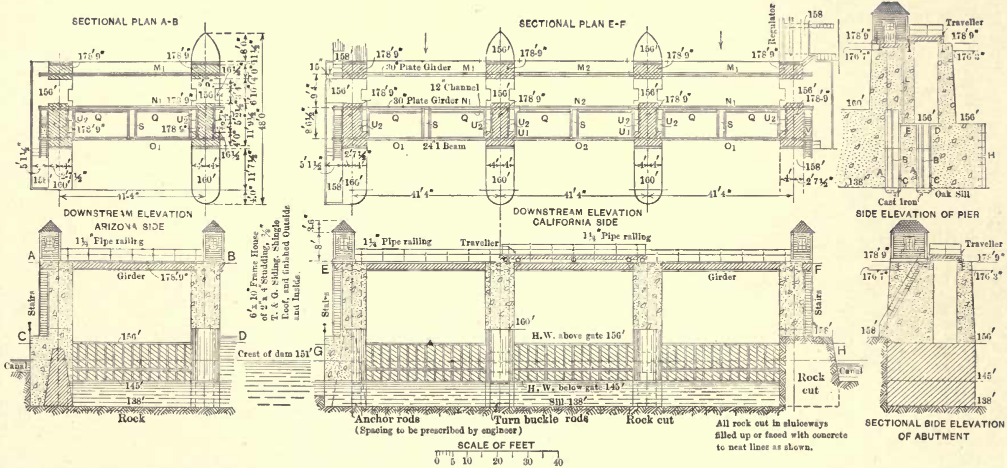


FIG. 8.—Plan and Elevation of Sluice-Gates, Laguna Dam, Colorado River, California.

a velocity near one foot per second and drops its heaviest sediment. This is sluiced out periodically by opening large sluice-gates which make available for sluicing purposes all the head afforded by the dam, which is about 10 feet at ordinary stages and less at high water. This usually generates velocities of from 15 to 20 feet per second.

The water is taken into the canal over an adjustable weir of such length that a comparatively thin sheet flows over it, carrying only the smaller and lighter particles of sediment, which are for the most part carried by the canals upon the land, where they are of value for fertilizing the fields.

The sluiceways are both built in rock which was so badly disintegrated that it was necessary to line them heavily with concrete throughout. The California sluiceway has a bottom width of 116 feet. It has three sluice-gates of the Stoney type, built of steel, operating on cast-iron rollers, with a height of 18 feet and a span of 35 feet; the piers have a total height of 41 feet above the floor of the sluicing channel. The gates are electrically operated from a 25-kilowatt generator actuated by a gasoline engine.

The sluiceway on the Arizona side, which serves a much smaller canal, is 40 feet in bottom width, and is controlled by a single gate, similar in design to those above mentioned.

The construction of the Laguna Dam and sluiceways was let by contract in 1905, but, owing to financial difficulties, was abandoned by the contractor and finished by Government forces.

The material and supplies used by the contractor were delivered at Yuma by rail and shipped up the river by steamer. The swift current and shoal and shifting channel of the river made this shipment so difficult and uncertain that team hauling was resorted to, with no better success, owing to bad roads and scarcity of teams. When the United States took over the work a railway was built on the levee on the California side, from Yuma to the Laguna Dam, and supplies were delivered at the dam site by rail.

The rock for construction was obtained at the ends of the dam, but was so badly decomposed that the waste was large and great difficulty was encountered in obtaining a sufficient quantity of sound rock for the purposes. The rock was loaded upon cars by means of derricks and hauled to the work with dinky locomo-

tives. The concrete was similarly transported from mixers near the quarries.

To protect the work from high water, cofferdams were built above and below the dam site with earth and waste from the quarries. The excavation into the alluvial valley for the dam structure was made partly by teams, but mainly with suction dredges, actuated by gas engines using distillate for fuel, which was obtained from the Pacific Coast, at an average cost of ten cents per gallon at the work.

The cofferdams were advanced from both sides of the valley until the river channel was reached, leaving a gap of about 800 feet. The sluiceways at both ends were finished and put in shape to carry the stream past the dam site.

A trestle was built across the river above the line of the upper cofferdam and the railroad track carried across the trestle and connected with quarries at each end of the dam. The available equipment was then put to work night and day to dump rock and spoil from the quarries into the river as rapidly as possible. By pushing this work faster than the river could carry the rock away, the water was steadily raised until it flowed through the sluiceways and stood then 11 feet above its previous level. This operation required 14 days. In a similar manner, but more easily, the lower cofferdam was built, and the river channel was then unwatered. Over 81,000 cubic yards of rock were dumped from these trestles.

For mixing, concrete rock was obtained from the ends of the dam and cement was shipped from Iola, Kansas, and from the Pacific Coast. The price of cement ranged from \$2.84 to \$3.53 per barrel on the work. The sand found locally was extremely fine and was supplemented by crushing granite between rolls to supply coarser particles. The proportions of the concrete were 1:3:7. The mixing was all done by machinery.

The original design contemplated piling only under the crest wall, but the treacherous nature of the foundation rendered it necessary also under the other walls in places.

The excavation for the sluiceways and canals furnished so little good rock that it became necessary to open quarries at other points, and the waste from these was large. This greatly increased the rock excavation.

During the closure of the river a heavy flood of considerable

duration occurred which scoured out the river and increased the rockfill. The earth excavation was also increased by caving banks and uneven dredging.

These changes from the original design affected the quantities as follows:

	As Designed, Cubic Yards	As Executed, Cubic Yards
Rock excavation	305,000	444,600
Earth excavation	282,000	346,900
Rockfill in dam	305,000	375,000
Concrete	27,150	76,000
Rock paving	80,000 Sq. Yds.	5,300 Sq. Yds.
Sheet piling	53,000 L. Ft.	82,800 L. Ft.

The common labor employed on the dam was mostly Mexicans and Indians, with a few white floaters in the winter. The skilled labor, foreman and mechanics, were mostly white.

Cost of Laguna Dam and Headworks

Laguna Dam:				
Excavation, Class 3,	307,746 cu. yds.	at $2.075		$638,807
" Class 2,	114,746 "	" 1.17		134,143
Rock in dam,	260,697 "	" .798		208,060
Rock paving,	5,391 sq. yds.	" 1.702		9,175
Concrete core-walls,	15,718 cu. yds.	" 11.318		177,905
Concrete paving,	26,598 "	" 9.272		246,620
Sheet piling,	32,776 feet	" 1.297		42,530
Protection, clearing, cleaning up, etc.				210,052
Administration				5,538
Total, Laguna Dam				$1,672,830
Sluice and regulator-gates, Arizona side			$119,100	
Sluice and regulator-gates, California side			232,725	351,825
Total				$2,024,655

CANAL SYSTEM

The main canal of the Yuma Project heads at the California end of the Laguna Dam, and follows the margin of the Valley for a distance of 10 miles to a point 3 miles due north of Yuma. Here occurs a drop of 10 feet, and the canal runs directly to the Colorado River, which it passes under through a pressure tunnel

about 100 feet below the river level. A short distance below this point the canal divides, one branch following the foot of the mesa and the other traversing the high ground near the river. Both branches extend nearly to the Mexican boundary and command all the irrigable land in the lower valley.

The eastern branch will also carry water to be lifted about 80 feet to the top of the mesa, where about 40,000 acres may eventually be irrigated.

At its head the main canal has a capacity of 1,700 cubic feet per second, has a bottom width of 65 feet, a water depth of 7.2 feet, and a slope of .000175, which will give it a mean velocity of about 3.5 feet per second. This section continues through the rocky hills a distance of a mile and a half. When the open valley is reached, the canal widens to 107 feet on the bottom with a depth of 7 feet and a slope of .00005, which gives a mean velocity of about 2.5 feet per second, and this velocity is approximately maintained as a minimum throughout the system, except through the siphon at Yuma, where the velocity is greatly increased.

At the point where the canal turns away from the river 1½ miles below the head a sluiceway is provided by opening which high velocities can be induced in the main canal above the sluice, and also for a short distance below, in order to clear it of accumulations of sediment.

Laterals are taken out of the main canal for the irrigation of the valley on the California side, and on reaching the siphon the capacity is 1,400 cubic feet per second.

About 10 miles below the heading, where the main canal leaves the foot of the mesa and turns southward toward Yuma, a drop of about 10 feet in the water level occurs to bring the canal to the level of the lower valley. It has been proposed at this point to develop hydro-electric power to be transmitted to a point below Yuma and used for pumping water from the main canal about 80 feet to the top of the mesa, for the irrigation of 30,000 to 40,000 acres of land. This drop is in the form of a siphon spillway. It contains ten siphons which can be adjusted to discharge at different levels, and all employed when the canal is running full. Their combined capacity is 2,500 cubic feet per second, and they serve to keep the water above at nearly a constant level. The structure is of reinforced concrete and cost about $23,000. Plan and section are shown on page 41.

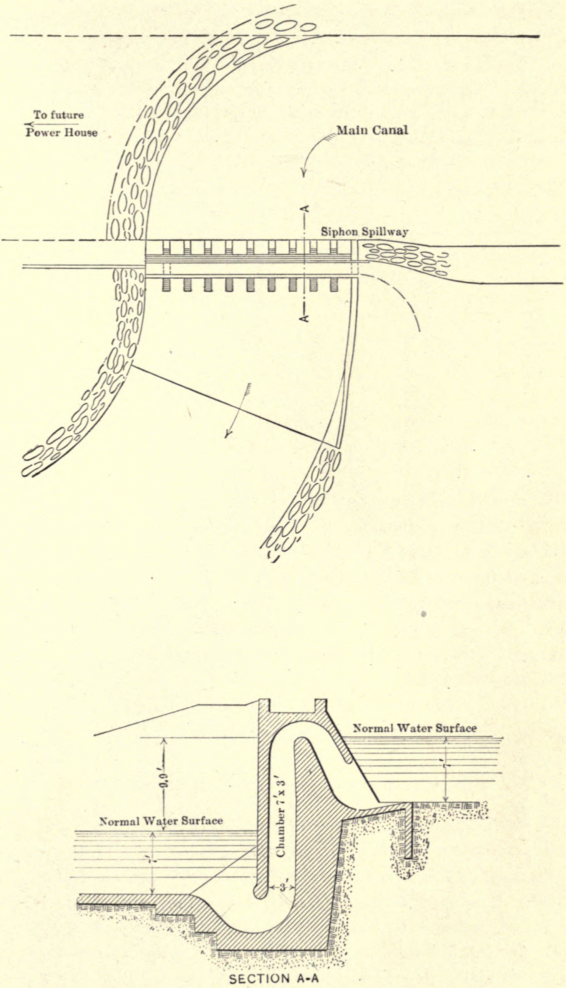


FIG. 9.—Plan and Section of Siphon Spillway.

The first section of the California Main Canal, extending from Laguna Dam to the heading of the Indian Reservation Canal, a distance of 7,600 feet, was mostly through foothill country, involving a large amount of heavy cutting and rockwork. 143,952 cubic yards were done by steam shovel and cost $87,825, or 61 cents per cubic yard. 84,945 cubic yards were done with teams for $29,000, or 34 cents per cubic yard.

The second section was divided into six schedules, as follows:

Schedule	Length, Feet	Yardage			Overhaul	Cost
		Class 1	Class 2	Class 3		
1	9,900	214,164	2,399	1,703	.....	$46,521
2	7,500	206,812	....	12,059	.....	46,995
3	7,500	218,198	....	.....	10,096	46,664
4	7,500	212,193	....	.....	1,652	42,538
5	7,500	213,272	23	.....	.....	44,090
6	8,000	228,904	3,822	1,540	.....	49,973

Section 3 included the canal from the siphon spillway to the Colorado River, a distance of 16,000 feet. It had a bottom width of 80 feet, a depth of 7 feet, side slopes 2 to 1, a gradient of .0001, and capacity of 1,400 cubic-seconds. The first part of this work in economic cut included 297,651 cubic yards and cost $52,457, or 17.6 cents per yard. The second part involved a heavy embankment across the Big Slough and a long haul with scrapers. It involved 68,523 cubic yards and cost $26,939, or 39.3 cents per cubic yard. There were also 12,000 square yards of riprap, costing $16,157, or 1.34 cents per square yard.

STRUCTURES ON CALIFORNIA MAIN CANAL

Seven thousand eight hundred feet from the dam is the heading of the Indian Reservation Canal, with a capacity of 250 cubic feet per second. It is a reinforced concrete structure containing four cast-iron hand-operated gates, each 4 × 4 feet, and a bridge over the branch canal is included in the same structure, costing $4,138.

In the same vicinity is a check and bridge across the main canal. The check contains seven openings controlled from the bridge by stop planks.

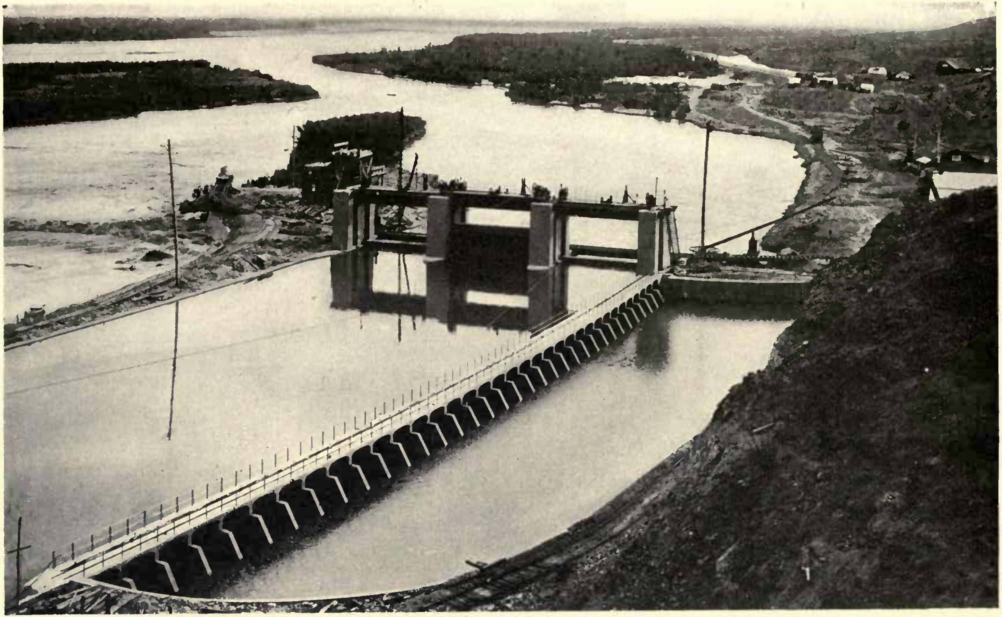


FIG. 10.—Regulating Gates and Sluice-Gates, Yuma Main Canal.

The main canal and structures cost as follows:

Location and designs	$20,172
Excavation, Class 1, 1,744,672 cu. yds. at 21.8 cents	381,337
" Class 2, 7,646 " " 28.2 "	2,150
" Class 3, 147,195 " " 61.2 "	90,035
Riprap, 9,292 sq. yds. at $2.46	22,887
Repairs	3,050
Wooden bridge and check	574
California road	418
Concrete check and wasteway	28,838
Siphon spillway, first construction	13,938
Bridge and check	5,360
Drainage culvert	7,174
Picacho Bridge	4,159
Powell Bridge	2,929
Yuma Main Canal, California, total	$583,021

Yuma Pressure Conduit.—The pressure tunnel under the river at Yuma is 1,000 feet long, circular in shape, and 14 feet in diameter. It has a vertical shaft at each end and at full capacity will have a velocity of 9 feet per second.

In considering the pressure tunnel or siphon to convey the main canal from the California to the Arizona side of the river, the question naturally arises why the water for the lower lands in Arizona is not taken from the Arizona end of the Laguna Dam, avoiding thereby the crossing of the Colorado. This alternative was carefully considered and was indeed the first plan proposed and estimated. A glance at the map will show that the distance from Laguna Dam to Yuma by the California Canal is much shorter than the contour on the Arizona side. The crossing under the Colorado is 1,000 feet long, between permanent banks, while the Arizona Canal would involve a crossing of the Gila River at a point where no permanent banks were available, and where levees would be required to control the river, and the crossing structure would have to be at least 3,000 feet in length. It also involved either a tunnel or a long heavy rock cut through the mesa east of Yuma. The California route was therefore both safer and cheaper, and being much shorter consumed less head, and thus secured an important power site not available on the Arizona side.

A flume crossing of the Colorado at grade is impracticable

FIG. 11.—Reservation Heading, Junction of Main and Reservation Canals. Yuma Project.

because the canal, held as high as the level of the valley will permit, reached the river with bottom elevation at 125 feet above sea level and water surface at 132. The surface of the Colorado in flood may lie anywhere between 125 and 134, and thus its channel would be blocked by the flume.

Borings showed the presence of a soft seamy sandstone at a depth in midstream of 50 feet below low-water level, dipping toward the north to a depth of 80 feet below ground surface at the northern intake. Overlying the sandstone and forming the river bed is a very fine sand.

At each end of the tunnel a shaft was sunk by carrying down a concrete caisson 17 feet inside diameter on the California side, and 23 feet in diameter on the Arizona side, from which it was expected to drive the tunnel. Each caisson was provided with a cutting edge in the form of a steel plate ¾ inch in thickness and 3½ feet wide, reinforced with channel and plate. The concrete sloped from this steel edge to a thickness of 5 feet, which it held for a height of 4 feet, and was then reduced by offset to 3½ feet.

These caissons were sunk first by excavating the material within and under the cutting edge with hand tools, keeping the water down by means of pumps. At length the difference of pressure outside and inside led to "blows" or sudden inflows of sand and water in large quantities until further progress by this method was stopped. The caisson was then allowed to fill with water, and the pressures being thus equalized the blows ceased. A clam-shell dredge was employed to dredge the material from inside the caisson, and heavy weights of steel rails and cement were employed to force the caisson down. These methods were supplemented by jetting water around the circumference to overcome the skin friction and by "shooting" the material under the cutting edge where the dredge could not reach. Divers were employed to place shots below the cutting edges.

At last the caissons were sunk to the required depth, and efforts were made to consolidate the quicksand along the section of the tunnel by grouting it, so that the caisson could be opened and excavation carried on. After numerous abortive attempts these efforts were abandoned and the pneumatic process resorted to. Air locks were installed, and pressures up to 32 pounds per square inch were used. The excavation of the upper half of the

tunnel required 27 to 28 pounds, and after this was completed a short distance the pressure was increased to 32 pounds and the lower half excavated. Steel rings composed of shapes 1 × 3 feet

FIG. 12.—Yuma Pressure Tunnel, under Construction.

were used as temporary lining for the arch immediately behind the excavation, and a concrete lining completed the work.

The rock in which the tunnel is located is a soft porous sandstone, containing many fine seams, through which the compressed air escaped rapidly. In the interval between the excavation of the rock and the placing of the concrete lining, it was necessary to keep the unlined rock plastered with clay to prevent the escape of air.

The tunnel is designed to carry about 1,400 cubic feet of water per second with a loss of head of 2 feet. It is circular in cross-section, with a diameter of 14 feet. The concrete lining is 24 inches in thickness. The shaft on the California side of the river has a diameter of 14 feet, and that on the Arizona side is 20 feet in diameter. The tunnel was driven entirely from the Arizona heading.

COSTS OF PRESSURE CONDUIT

Boring and testing	$ 2,375
California shaft	117,106
Arizona shaft	147,592
Pressure tunnel	410,575
Total	$677,648

Yuma Valley Canals.—The main canal heading at the Arizona shaft has a capacity of 1,400 cubic feet per second, a bottom width of 78 feet, water depth 7 feet, side slopes 2 to 1, and gradient of .0001. It extends about 5,000 feet to the intersection of Second Street and Eleventh Avenue, where it divides into two branches, the East and West Canals, each of which is provided with control gates set in a masonry structure. Below this point, the East Branch has a capacity of 840 cubic feet per second, and the West Branch 520 cubic feet per second.

The ten main diversions from the East Branch Canal are as follows:

Name	Miles Below Branch	Capacity, Second-Feet	Size Below		Depth	Slope
			Capacity	Bottom Width		
Mesa (proposed)	2½	500	340	40	4	.0002
Central Canal	5½	160	200	18	4	.00025
Donovan "	6	20	200	18	4	.00025
Yarwood "	6½	30	160	14.5	4	.000275
Hopkins "	7	20	160	14.5	4	.000275
Somerton "	10	80	80	11.5	3	.0003
Havens "	11	20	80	11.5	3	.0003
Harris "	12½	20	60	11.5	2.5	.00032
Stevenson "	16	20	40	7.6	2.5	.00033
Thurman "	16½	20	20	5	2	.0004

These branches are all taken out through reinforced concrete structures, to and including the Somerton diversion. The small structures below that point are of wood.

The quantities and cost of the main structures along the East Branch Canal are shown in table on opposite page.

The West Branch Canal begins with a capacity of 520 cubic seconds, where the bottom width is 40 feet, the water depth 5 feet, and gradient .0002. It decreases as laterals are taken out, and is in general designed and constructed along the same lines as the East Branch Canal.

Name	Excavation, Cubic Yards	Reinforced Concrete, Cubic Yards	Riprap, Square Yards	Cost
3rd Street Bridge	1,200	304	204	$8,734
8th Street Bridge	175	304	327	9,334
Drop below mesa div	560	467	909	13,559
Canal head and check	300	184	279	6,023
Drop below Donovan	125	52	219	3,615
Yarwood heading	60	40	50	2,000
Hopkins head and check	85	65	160	3,125
Somerton head and check	100	100	200	4,475

Lateral System.—The lateral distribution system on the Yuma Project is designed and built for irrigation by the rotation system. It is customary to deliver to each irrigator a head of from 10 to 12 cubic feet per second for such time as may be required to irrigate his fields and then turn the water to the next irrigator, leaving all other sublaterals dry. This is economical of water, minimizes seepage losses, and, above all, economizes the irrigators' time. It requires, of course, the sublateral system and the farm ditches to be constructed of a capacity to handle such heads.

YUMA PROJECT DISTRIBUTION SYSTEM

Reservation Distribution System:	
Location of canals	$ 1,480
Excavation, all classes, 868,312 cu. yds. at 25 cents	218,286
Structures	82,207
Repairs	20,513
Total	$322,486
Gila Valley Distribution System:	
Location of canals	$ 3,791
Excavation, all classes, 393,000 cu. yds. at 28 cents	109,505
Installation pumping plant	10,490
Repairs	6,224
Rainwater flume and bridge	2,032
Sluiceway structure	6,068
Levee Canal Turnout	704
Adkins Turnout	344
Osmond Turnout	462
Boyle Turnout	655
McPherson Turnout	1,827
Main Canal Check	1,036
Wooden structures	10,330
Total	$153,468

LEVEE SYSTEM

The bottom lands of the Yuma Valley are above the level of ordinary river stages, but they are subject in their natural state to overflow at high flood stages of the river. To prevent this, an extensive system of levees has been designed along the banks of the Colorado from Laguna Dam to the Southern Pacific Railway on the west side, and to the mouth of the Gila on the east side. Also from the Yuma Mesa along the east bank to the Mexican boundary. The right bank of the Gila is also to be protected from its mouth to high ground near its emergence from the hills.

The levees are designed to stand about 3½ feet above maximum floods in the river. The side slopes are 3 to 1 on both sides, with top width of about 10 feet. Some of the earlier levees were given slopes of 2½ to 1 on the land side, but the tendency to slough when saturated led to the adoption of the flatter slopes on later work. As a rule a cut-off trench is provided under the water slope of the levee and filled with good material. Material for construction of the levees is obtained from borrow pits on the river side, which are discontinuous so as not to induce erosive currents. As a further precaution in this direction, low brush dikes are constructed as spurs on the river side of the main levee.

The total length of levees is about 70 miles. About three-quarters of this has been constructed, requiring the movement of about 2,700,000 cubic yards of earth, at an average cost of 25 cents per cubic yard.

These levees are, of course, subject to attack from burrowing animals, but the main menace is from erosion by the meandering stream, which may undermine the levee without even wetting its base. Protection against this menace is difficult and expensive. The method so far employed is to blanket the levee on the water slope with a large amount of rock, which is dumped from cars hauled to the spot on a railway provided on the crown. When the current attacks the bank at the foot of the rockfill, the rock falls to the bottom of the caving bank and checks the erosive action. Additional rock is supplied until the erosion ceases and the river flows along the rockfill and parallel to it. This method has been effective in all cases, but requires a railroad the entire length of each levee, communicating with the rock quarries at Laguna Dam.

FIG. 13.—Colorado River Levee, Showing Spur Dikes of Brush.

DRAINAGE

The usual drainage problems that accompany the normal irrigation projects are accentuated in the Yuma Valley by the fact that the river banks and the valley are connected by a substratum of pervious material so that at times of high water in the river the water table is raised by percolation from the river. An elaborate system of drains becomes imperative therefore, and these have been, or are being, constructed by means of drag-line scrapers, and the drainage water carried down the valley and discharged into the river. It becomes necessary at times of high water to pump the water over the levees. At this writing 19 miles of open drains have been constructed at a cost of about $163,000, and 8 miles of closed drains costing $70,000.

The original plans and early construction on the Yuma Project were conducted by Homer Hamlin under the direction of J. B. Lippincott as Supervising Engineer. In 1905 Mr. Lippincott was succeeded by Louis C. Hill and Mr. Hamlin by F. L. Sellew, who built the main canals, and the pressure tunnel under the Colorado River. E. D. Vincent was the Construction Engineer on the Laguna Dam.

CHAPTER IV

ORLAND PROJECT

RELATION TO SACRAMENTO PROJECT

The Sacramento River rises in Northern California and flows southward nearly 250 miles to Suisun Bay, into which it empties. It drains the western slope of the Sierras through its tributaries, the American, Feather, Yuba, and Bear Rivers, and numerous smaller streams. It also drains the eastern slope of the Coast Range through numerous creeks, of which the principal are Stoney, Cache, and Puta Creeks, its total drainage basin covering about 28,000 square miles.

The lower part of the basin is very flat, and over 1,000,000 acres of its area are subject to frequent overflow, to prevent which is one of the interesting hydraulic problems of the day. The entire valley is arid and requires irrigation for successful agriculture, although winter wheat has been extensively grown in parts of the valley for many years.

The most important elements in the solution of the flood problems are levees and by-passes; but the storage required for extensive irrigation and its extension to the practicable limits for flood regulation is a possible contribution to the problem that is worthy of consideration, and the proper handling of the river system thus involves the consideration of irrigation as well as flood control.

The irrigation problems involve storage on the Sacramento itself and also on many of its tributaries. Some reconnaissance has been done over most of the watershed, resulting in the adoption for first construction of a small project on Stoney Creek for the irrigation of lands at and around Orland.

This project provides for the storage of water on Little Stoney Creek. The stored water is released from this reservoir when needed and flows down Stoney Creek to Miller Buttes, where it is diverted on the south side of the creek, and four miles below a canal is diverted on the north side. The area irrigated is 20,000

acres, of which 13,000 are on the south side of Stoney Creek and 7,000 acres are on the north side.

EAST PARK RESERVOIR

This reservoir is located on Little Stoney Creek below the junction with Indian Creek and about three miles above the mouth of Little Stoney Creek. The drainage area directly tributary to it is 102 square miles, and in addition to this it is fed by a

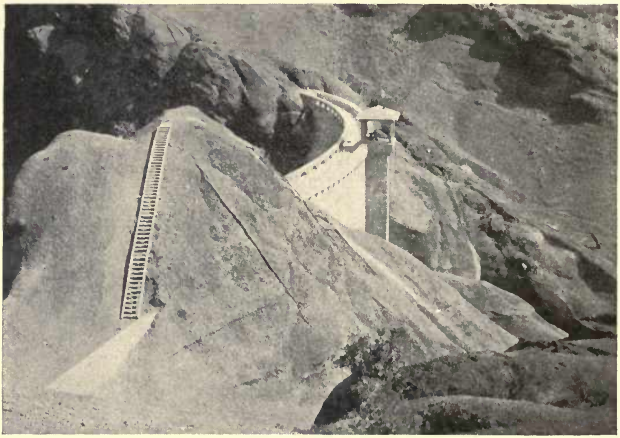


Fig. 14.—East Park Dam, Orland Project.

supply canal from the main Stoney Creek, 6½ miles in length, with a capacity of 200 cubic feet per second. The reservoir has a superficial area of about 1,900 acres, and a capacity of 51,000 acre-feet.

East Park Dam.—The dam forming the East Park Reservoir is located in a gorge of conglomerate and is built of concrete on a radius of 275 feet. It is 140 feet high above foundation and has a top length of 249 feet. It has a thickness at top of 10 feet and at base of 86 feet. Twenty feet above the bed of the river is a circular conduit which constitutes the main outlet. This is controlled by two sluice-gates each 4 × 5 feet, set in tandem, 7 feet apart on opposite sides of a gate tower.

From the foundation of the dam to the top of the outlet conduit, 25 feet above the river-bed, the dam is built as a monolith. Above this point, radial contraction joints are provided at forty-foot intervals, and in the upper 50 feet at twenty-foot intervals. Each joint has a dowel, and back of each dowel is a drain leading to the down-stream toe of the dam, and also extending to the top so that it can be flushed out.

The spillway is located in a saddle about $\frac{1}{4}$ mile from the dam. It is a concrete structure founded on hard shale. It is a weir consisting of nine semicircular arches resting against piers 8 feet wide. The arches have a radius of $13\frac{1}{2}$ feet, and the whole structure is curved to a radius of 474 feet, its total length being 460 feet. It is designed for a capacity of 10,000 cubic feet per second with a depth of overflow of 3.7 feet. A water cushion is formed by a series of small weirs 2 feet high on radii of 29 feet, built down-stream from the main weir.

It was originally intended to incorporate in the concrete blocks of sandstone obtained from a quarry near by. Tests were made, however, on the available stone, and it was found that on being soaked in water and then dried it showed marked signs of disintegration. This tendency was also exhibited after incorporation of this stone in test blocks of concrete, and its use was abandoned.

Sand was obtained near the dam site, but was lacking in fine particles, which were added from a bar of fine sand occurring about half a mile away. The average mix was about 1:3:7, the limiting size of gravel being 3 inches.

The dam was built by contract, there being sixteen bids ranging from $65,000 to $315,000.

At four points around the reservoir earthen dikes were required to close low saddles. These varied in height from 3 to 20 feet, with top widths of 20 feet, and slopes of three to one on the water side and two to one on the dry slope. Both slopes were protected by rock pitching one foot deep.

The construction plant was installed a short distance below the toe of the dam, on the left bank of the stream. A 20-cubic-foot measuring hopper having three compartments was used to proportion the aggregates, which were discharged into a 20-cubic-yard rotary mixer operated by a vertical steam engine. The mixer discharged the concrete into dump cars with sloping bottoms

which were discharged by means of sliding doors. The cars were supported on a trestle built on the south abutment of the dam. The concrete in the base of the dam was conducted to place from the cars by sectional iron tubes, from which sections were removed

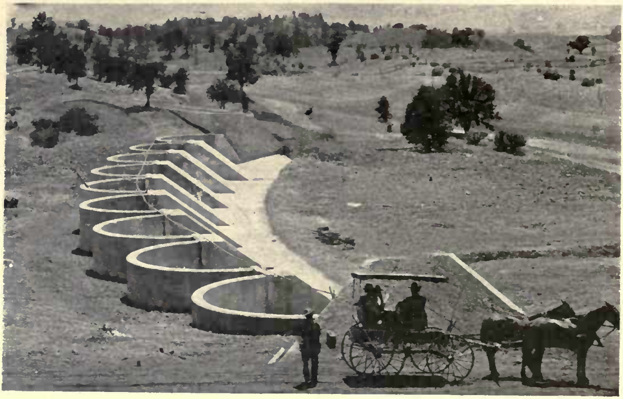


FIG. 15.—East Park Reservoir Spillway, Orland Project.

as the concrete rose. Above the river bed the concrete was hoisted to ore cars running on tracks built into the concrete. A 2-foot opening was left in the concrete at the river-bed, to dispose of the water, and this was accomplished until the main outlet was built, 25 feet higher. Above this point, a section of 40 feet between contraction joints was left open to care for floods during the winter. After May 15, 1910, until the completion of the dam in June, concreting was carried on only between the hours of 7 P.M. and 7 A.M. on account of the high temperatures of the daytime, the concrete being covered with wet burlap during the day.

The creek was diverted by means of a cofferdam and conducted below the dam site through a wooden flume. Excavation in the river bed began in June, 1909. A drag scraper drawn by a cable on a hoisting drum actuated by steam was employed in excavation, and two centrifugal pumps, a 5-inch and a 6-inch, were used to keep the water down.

All loose material and detached or decomposed rock were removed and vertical channels 6 inches deep and 4 feet wide were cut in the abutments to make bond with the concrete. No explosives were allowed on the abutments and all solid rock excavation was done by gads, drills, and hammers. Large boulders encountered were broken by explosives.

Cost of East Park Reservoir

Examination	$ 4,061
Clearing site	16,260
Land purchases	72,209
Excavation, all classes, 20,248 cu. yds	29,003
Concrete, 15,203 cu. yds	137,670
Reinforcement, 16,075 lbs. at $0.059	1,002
Gates, including installation, 23,290 lbs. at $0.137	3,361
Extra work	8,415
Earthwork in dikes, 3,961 cu. yds. at $0.37	2,678
Riprap on dikes, 747 cu. yds. at $1.92	1,503
Total for Reservoir	$276,162

FEED CANAL

The Orland Project, like most of the Reclamation Projects, was planned with very short available records of water supply. At the East Park Dam Site, the run-off was measured for 1907, 92,000 acre-feet; 1908, 39,000 acre-feet; and 1909, 171,000 acre-feet. With the flood waters of the Big Stoney Creek available for diversion in the spring and the storage capacity of 46,000 acre-feet, it appeared that the water supply was ample for the 14,300 acres included in the project.

The season of 1911–12, however, furnished to the reservoir only 11,400 acre-feet, and of 1912–13 only 18,400 acre-feet. Had the entire project been using water, serious shortage would have occurred, and it was evident that some means of increasing the stored supply must be found. The means adopted was to build a feed canal from Big Stoney Creek to the reservoir, a distance of 6½ miles, and to increase the storage capacity 5,000 acre-feet by building up the spillway 18 inches. These improvements were carried out in 1914.

The diversion dam for the feed canal is a concrete arch built to a radius of 100 feet, with a crest length of 155 feet and a maxi-

mum height of 44 feet. Its greatest thickness is 6½ feet, and this diminishes to 3½ feet near the top, the batter on the water side being 1:10, and on the lower face being vertical.

The crest of the dam is curved down-stream in vertical section,

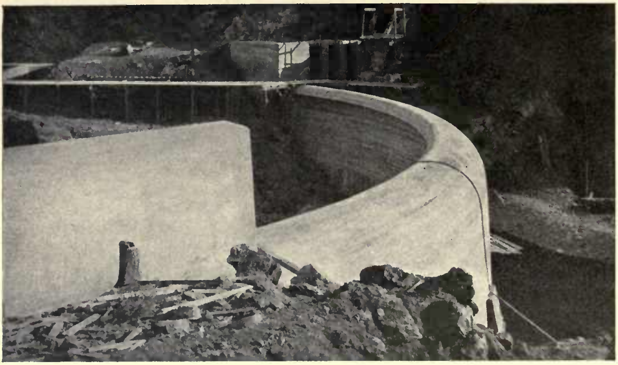


FIG. 16.—Diversion Dam, East Park Feed Canal, Orland Project.

in order that the overflow may fall free from the dam and cause no vacuum.

The head-gates of the canal are submerged when the dam overflows, so that fluctuation of head causes less variation of discharge than if they were not. The canal is provided with an overflow weir to dispose of surplus waters; to secure still closer regulation, a siphon is provided which begins to discharge when the water stands at .2 foot above the crest of the weir, and continues until it falls below the crest. By these provisions the regulation of water into the feed canal is automatic, and no attendance is normally required at the head-gates.

COST OF FEED CANAL, DAM, AND STRUCTURES

Item	Unit	Cost to United States Quantity	Unit	Total
Diversion Dam and Controlling Works:				
Excavation Class A	Cu. Yd.	1,227	$ 0.56	$ 688.18
Excavation Class B	"	1,656	2.24	3,715.61
Concrete	"	1,776.7	12.89	22,289.34
Reinforcement	Lb.	12,573	.0473	610.10
Handling water	......	......	......	2,359.50
Total Dam and Head-works				$29,662.73

COST OF FEED CANAL, DAM AND STRUCTURES—*Continued*

Item	Unit	Cost to United States Quantity	Unit	Total
East Park Feed Canal:				
Land	Acre	91	$116.17	$10,571.40
Excavation Class 1	Cu. Yd.	77,904	.2236	17,422.94
Excavation Class 2	"	131,073	.3354	43,963.43
Excavation Class 3	"	11,719	.7824	9,168.63
Overhaul	"	2,401	.0224	53.66
Extra work	......	......	......	138.93
Total East Park Feed Canal, exclusive of land				$70,747.59
Canal Structures, Lining and Alterations to East Park Spillway:				
Excavation Class 1	Cu. Yd.	2,913	$0.45	$1,307.01
Excavation Class 2	"	5,769	1.62	9,320.53
Excavation Class 3	"	6	3.26	19.53
Puddling	"	409	.11	46.18
Concrete	"	2,777	12.11	33,629.45
Dry paving	"	36.9	2.59	95.43
Placing reinforcing steel	Lb.	48,536	.044	2,162.75
Erecting gates, etc	"	8,243	.076	631.08
Erecting lumber in structure	M. Ft.	21.472	60.57	1,300.56
Wyands Cr. Culvert	......	......	......	1,017.81
Extra work Contract No. 546	......	......	......	3,892.19
Total Structures				$53,422.52

MILLER BUTTES DIVERSION

The South Canal of the Orland Project heads near Miller Buttes, about 10 miles northwest of Orland, where Stoney Creek is held on both sides by high land. Its high-water bed is about 900 feet wide, and consists of coarse gravel and boulders. The diversion dam is of the simplest character, consisting merely of a double row of round piles driven in the coarse gravel of the river-bed, flush with the surface except in low places, and a timber bulkhead fastened to these piles, extending about 6 feet below the top. An apron of large rock was placed on the down-stream side of this bulkhead.

The South Canal was designed for a normal capacity of 135 cubic feet per second, having a bottom width of 12 feet, and 3 feet of water depth, with a grade of .0008. No checks were required on this canal. The drops were each provided with a notched weir to maintain proper depth in the canal.

The North Side Canal heads about 3 miles below the South Canal heading. A small canal built on this alignment by private enterprise was purchased by the United States and enlarged to

a capacity of 80 second feet, for the service of about 7,000 acres of land, most of which is a clay loam, as distinguished from the more open soils of the south side. Its structures are simple, and present no points of special interest.

DISTRIBUTION SYSTEM

The canals and laterals of the Orland Project aggregate nearly 200 miles in length, and are designed for the delivery of water to the highest point of irrigable land on each 40-acre tract.

Fig. 17.—Fishway at Diversion Dam of Feed Canal, Orland Project.

There are about 1,400 structures of various kinds on this system, most of which are of standard design, and built of concrete. Excellent gravel was obtainable from Stoney Creek and from various gravel pits on or near the project.

In many places, the soil is gravelly and open, and as water is very valuable, a large part of the lateral system has been, and more will be, lined with concrete.

The standard lining for laterals is $1\frac{1}{2}$ inches in thickness. This was mixed in a small portable mixer driven by a 3-horse-power gasoline motor, and delivered charges of 3 cubic feet, using one-half sack of cement to each charge. The concrete was discharged into wheelbarrows, wheeled to the point of use, dumped into a convenient box, and shoveled on to the slopes, where it was tamped and finished with trowels. It cost

about 30 to 40 cents per square yard. On the main canal, the cost was 67 cents per square yard.

Delivery of Water.—The rotation method of water delivery was installed with the first delivery of water on this project and has been strictly adhered to.

For the most part single irrigating heads are run in the laterals during the rotation periods. The farmers themselves, commencing at the lower end of the lateral, make the changes until the head of the lateral is reached, at which point all changes are made by the canal riders. The farmer receives notice of time and length of run sufficiently in advance to be prepared for the water or to arrange for an exchange of time with his neighbor, should he so desire; such exchanges being permitted when they interfere with no one's time other than those who are parties to them. If the water user does not want the water to which he is entitled during any run, he notifies the canal rider to that effect before the water is turned into the lateral.

For orchard and furrow irrigation generally, water is furnished on demand, forty-eight hours' notice being required by the project office.

The "economical" irrigating heads as determined for this project are from 1 to 2 second-feet for orchard and cultivated crops and from 3 to 12 second-feet for flood irrigation; in the latter case the size of the head depending largely on the texture of the soil.

For flood crops delivery is made by schedule, the time elapsing between irrigating periods and the length of run depending on the season, texture of soil, crop, and the depth of water required at each irrigation.

The following tabulation gives the principal service periods and the depth of water allowed under each for irrigating flooded crops during the months of June, July, and August:

Texture of Soil	Rotation Period, Days	Depth in Inches	Head Second-Feet
Compact clay	7	1.8	3 to 4
Gravelly clay	10	2.5	5 to 6
Orland coarse gravel	14	3.6	8 to 10
Loam and sandy loam	21	5.0	8 to 12

$$\text{Length of run in hours} = \frac{\text{Depth in inches} \times \text{number of acres.}}{\text{Head in second-feet}}$$

The East Park Dam was constructed by W. W. Schlecht, under the direction of D. C. Henny, Supervising Engineer. The other main features of the project were constructed by A. N. Burch, the present Project Manager.

CHAPTER V

GRAND VALLEY PROJECT

ORIGIN AND HISTORY

Grand River has its source in the north central part of Colorado, near the Continental Divide, and flows in a general southwesterly course through canyons and gorges until about 40 miles before reaching the Utah line it emerges from the mountains and enters the famous Grand Valley, containing over 113,000 acres of irrigable land. In this valley it receives the waters of its main tributary, the Gunnison. Its drainage area above the Gunnison is about 8,600 square miles, of which over 8,000 is high mountain area tributary to the canal systems of the valley. The flow is greater than that of any other river of Colorado.

Irrigation in Grand Valley, Colorado, was early undertaken by private enterprise, and gradually expanded until all the bottom land easily reached by gravity from the river was entirely covered by irrigation canals. Water power was then developed and water pumped to the most accessible lands at the head of the valley which had shown their high value as fruit lands. The Reclamation Service began preliminary investigations in 1902 of a high-line canal for reaching the mesa lands in Utah just west of the State line. This reconnaissance showed the plan to carry the water to the high lands in Utah to be impracticable, but led to a recommendation to survey a less ambitious scheme for watering the high lands of the valley proper in Colorado. Local interests, however, favored construction under the district system and the Government project was abandoned. Later local efforts succeeded in developing a small district for pumping to the choice fruit lands in the head of the valley, and these were completely covered by this means. It was found impossible, however, to interest private capital in the scheme to water the relatively inaccessible lands in the western end of the valley, and in 1909 the Government was induced to undertake this task.

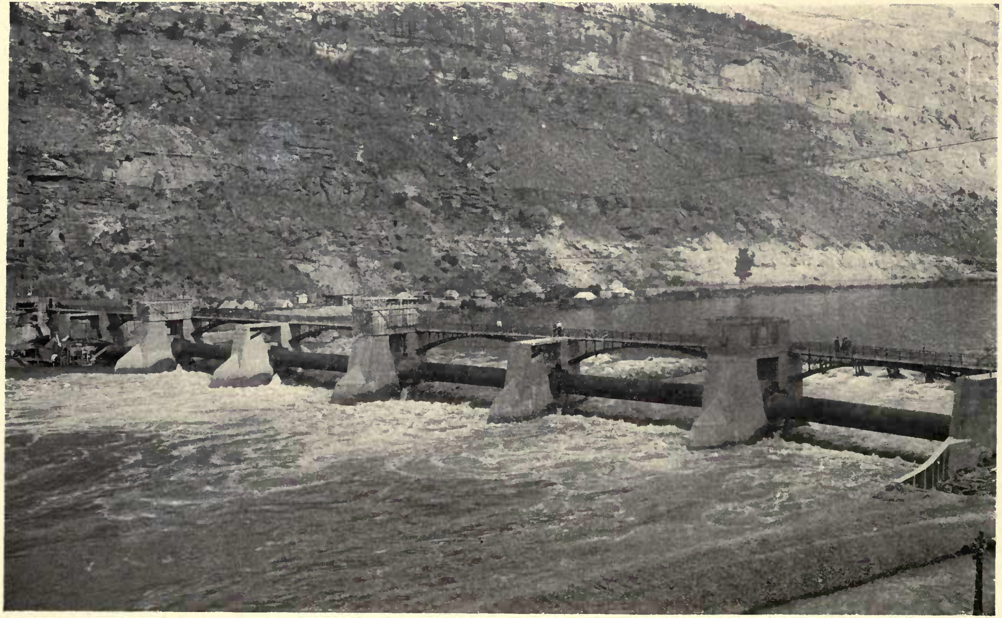


FIG. 18.—View of Rolling Dam, Grand River, Colorado.

The Grand Valley Project of the Government involves the diversion of the waters of Grand River by a dam located about 8 miles above Palisade, Colorado, into a canal on the north side of the river, for the irrigation of lands north and west of Grand Junction, Fruita, and Mack. The main conduit, for about 6½ miles through the canyon, consists of a series of tunnels and concrete-lined canals, crossing drainage by siphons or flumes, until a tunnel 7,000 feet in length emerges upon the valley northeast of Palisade. Here for a distance of 10 miles the location lies through the highly developed orchards of the pumping district where the land damages were very high. Thereafter the route winds through the adobe hills north of Grand Junction, reaching its first considerable area of new irrigable land after about 18 miles of heavy construction. From this point the canal extends for about 25 miles in a general northwesterly direction, irrigating a strip of land averaging about 2 miles wide, and then follows the contour around the head of the valleys of East and West Salt Creeks, making a total area of irrigable land reached by gravity of over 42,000 acres. In addition to this it is feasible to pump from the main canal to an additional area of about 11,000 acres, lying in four tracts above the canal and reachable with lifts varying from 50 feet to 175 feet.

The necessary power for pumping water to the higher lands is to be developed by carrying the necessary water from the head-works to a point above the heading of the next lower canal and there dropping through turbines the water to which the lower canal is entitled, and transmitting the power in the form of electrical energy to the pumping sites.

The project is planned to divert 1,425 second-feet of water at the head-works and, after allowing for necessary power development and for probable losses in transit, to deliver 530 second-feet to the land for the irrigation of 53,000 acres of land, or 1 second-foot to 100 acres. In case it be found impossible to attain so high a duty of water, it will be possible to eliminate some of the higher pumping lifts, and thus the water required for power and irrigation on the eliminated area will become available for the other lands.

GRAND RIVER DAM

In the diversion of Grand River the problem presented was to raise the level of the river at low stages sufficiently to send 1,425 cubic feet of water per second into the head of the main canal and yet at high water to pass a flow of 50,000 cubic feet of water per second without raising the water level to a point where it would endanger the road-bed of the Denver & Rio Grande Railroad adjacent. This required a movable crest upon a concrete weir as a sill.

The diversion dam developed is a concrete overflow base of ogee section with projecting apron, surmounted by a series of seven movable roller dams, six of which are 70 feet long and 10.25 feet high, over the dam proper, while the seventh has a span of 60 feet and a height of 15.3 feet, and is used to control the sluiceway.

The canal gates, nine in number, are parallel to the river, and the sluiceway roller closes upon a sill 5 feet and 1 inch below the sills of the other rollers, and 8.3 feet below the sills of the canal gates, so that gravel deposited in front of the gates can be sluiced out by raising the 60-foot roller, and thus a deep settling basin can be maintained in front of the gates, to prevent the river gravel from entering the canal. The hoisting apparatus for the sluicing roller is located on the right abutment of the dam, which serves also for the left abutment of the head-gate structure. The other six rollers are operated by three hoists located on alternate piers, each hoist serving two rollers. These piers are 10 feet wide and the other three are 8.25 feet wide. A steel truss bridge spans each opening. Each hoist is equipped with an electric motor receiving current from a gas engine in the gate house on the right abutment pier. A cut-off wall is located directly below the summit of the ogee, which is also the sill of the rollers, and is carried down 24 feet below that sill or about 14 feet below the natural bed of the river, which consists of sand and gravel, much of which is quite coarse.

The concrete protective apron in the sluiceway extends 100 feet down-stream from the dam, and terminates in a cut-off wall of concrete 3 feet thick carried 8 feet below the top of the apron. The concrete protective apron below the dam proper is carried down-stream 50 feet, and has a similar cut-off wall at its lower edge.

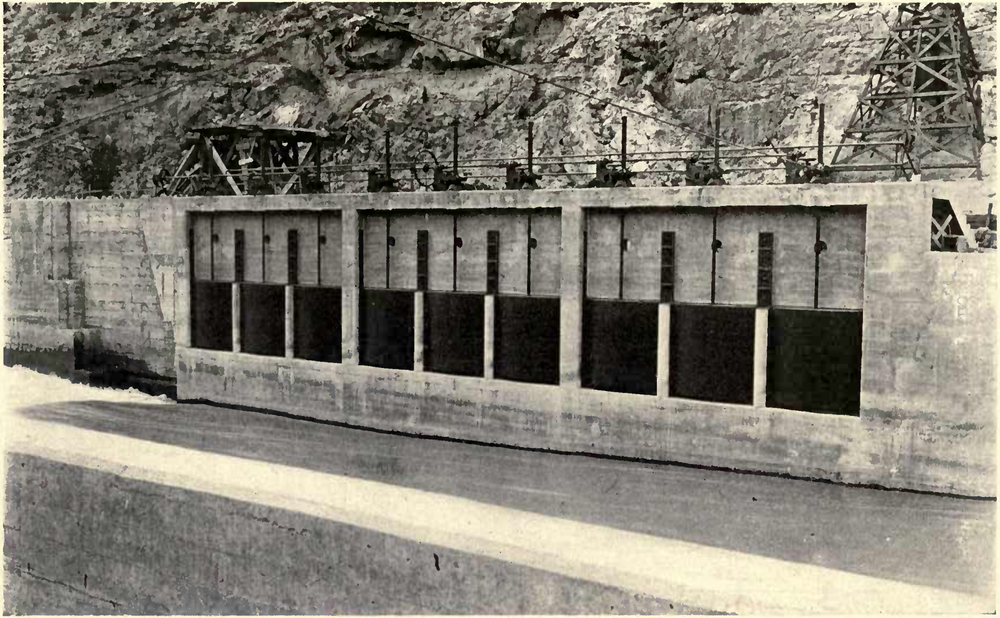


Fig. 19.—Head-gates, Grand Valley Canal, Colorado.

To check percolation under the dam, the up-stream side is covered by a thin apron 40 feet wide, and above this earth is

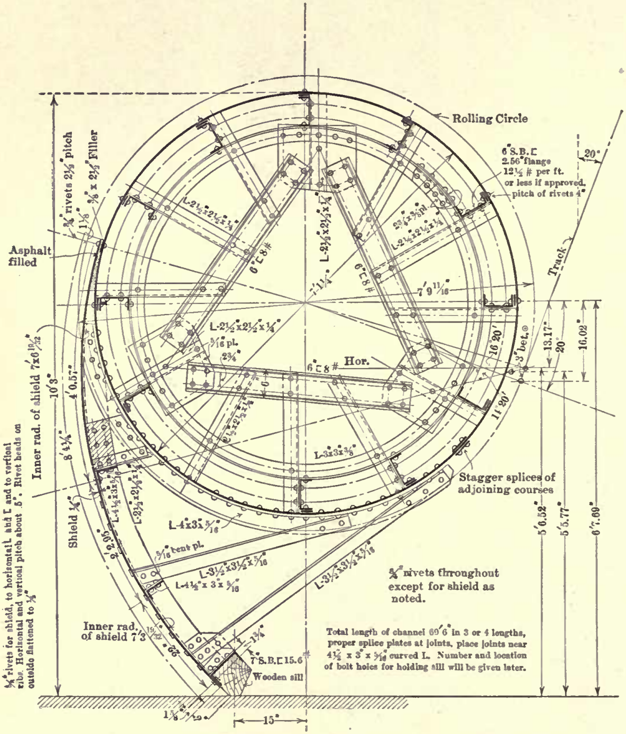


FIG. 20.—Section through Body of 70-foot Roller Dam, Grand River, Colorado.

sluiced in. The automatic silting of the dam will complete the process.

The total length of the diversion dam between abutments is 536.5 feet. When the rollers are closed at low river stage, it raises water about 20 feet above the general bed of the river.

The project canal heads at the right bank, and on the left is the

smaller canal of the Orchard Mesa Irrigation District. The plans are such that this canal can be supplied from the Government

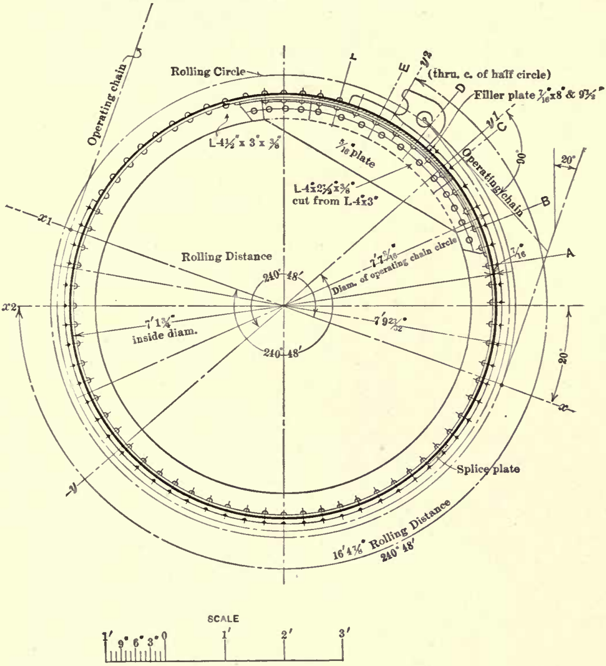


FIG. 21.—Section through Driven End of 70-foot Roller.

dam, thus providing a new heading, but for the present the canal is protected and allowed to flow in its original channel from the diversion dam above, undisturbed, past the Government dam.

MAIN CANAL

The main canal of the Government Project leaves the diversion dam with a capacity of 1,425 second-feet. Its bottom width is 38 feet, it has a water depth of 10.5 feet, and side slopes of 1½

to 1. The lower bank has a freeboard of 5 feet and a top width of 15 feet, while the upper bank has a freeboard of 3 feet and a top width of 10. Further down the side slopes are flattened to 2 to 1 and the bottom slightly narrowed. The estimated velocities are about 2½ feet per second, the slope being .000095.

At station 90 the conduit enters Tunnel No. 1, which is about 3,700 feet in length, and has a grade of .0007. The velocity generated in this tunnel is preserved at its exit in a concrete-lined channel for about 550 feet, where it enters a concrete pressure conduit passing under Jerry Creek, after which the conduit becomes an earthen canal. It passes under Coal Creek in a concrete inverted siphon, and enters Tunnel No. 2 about 21,000 feet from the head-gates. This tunnel is about 1,700 feet in length, and has a grade of .00071. After leaving Tunnel No. 2, the conduit is open canal for a distance of 1,600 feet, and then enters Tunnel No. 3, which is 7,000 feet in length, and from which the conduit emerges among the orchards of the Mesa County Irrigation District.

The canal construction of the canyon division above described was performed under contract, and consisted mainly in the moving of talus slope material of clay, sand, and boulders. The tunnels were built by Government forces and were all lined with concrete. They were excavated partly in miscellaneous talus materials, but mainly in sandstone or shale. In sandstone the section is a rectangle surmounted by a circular arch. In shale, due to the danger of swelling ground, the sides and bottom were given a curvature to bestow greater resistance to outside pressure, producing a shape similar to a horseshoe.

Through the orchard region the main canal is given a bottom width of 25 feet and a water depth of 8.5 feet. A freeboard of 7 feet is provided on the lower side, to guard against trouble due to the "settling" of the soil under the wetting of the canal. This is a phenomenon peculiar to the upper end of Grand Valley and not fully explained as yet. A limited area in the neighborhood of Palisade undergoes a subsidence in altitude when thoroughly soaked, as by irrigation. The amount of this subsidence varies from 1 to 5 or 6 feet, and requires extreme care in bringing land under irrigation. If the ground be not saturated uniformly it may subside more in one place than another, and the line of difference may be a well-marked step of several feet, after the

formation of which it is very difficult to restore the relative level of the ground necessary for irrigation. Even with great care in wetting, the ground often settles so unevenly as to cause much annoyance. The amount of settlement to be expected is very indefinite, and it is to avoid difficulties from this cause that so large a freeboard is necessary.

Costs to December 31, 1915, of Grand Valley Project, Colorado

Examination and surveys			$ 69,624
Diversion dam and head-works			489,376
Preliminary and general	$ 5,595		
Excavation, 55,788 cu. yds. at $2.53	140,013		
Concrete, 17,990 cu. yds. at $11.61	208,966		
Backfilling, 11,405 cu. yds. at $0.59	6,779		
Machinery and install., 823,718 lbs. at $0.097	80,068		
Embankment, 4,763 cu. yds. at $1.135	5,405		
Bridge (service), 97,311 lbs. at $0.083	8,031		
Riprap and paving, 7,660 cu. yds. at $4.51	34,519		
Main canal			1,924,037
Engineering and preliminary		$ 29,156	
Right of way purchase and fencing		240,134	
Right of way damages		21,407	
Priming and puddling		18,990	
Tunnel No. 1, 3,723 linear feet		267,164	
Excavation, 41,830 cu. yds. at $3.11	130,080		
Timbering, 3,723 lin. ft. at $7.33	27,294		
Lining, 8,410 cu. yds. at $9.78	82,290		
Approaches and portals, complete	27,500		
Tunnel No. 2, 1,655 lin. ft. at $70.61		117,867	
Excavation, 19,131 cu. yds. at $3.41	65,242		
Lining, 3,962 cu. yds., at $9.88	39,132		
Approaches and portals, complete	13,493		
Tunnel No. 3, 7,292 lin. ft. at $45.76		333,653	
Excavation, 46,806 cu. yds. at $4.48	209,674		
Lining, 13,792 cu. yds. at $8.27	114,120		
Approaches and portals, complete	9,859		
Division 1, Earthwork		125,610	
Culverts and bridges		31,214	
Wasteway		13,364	
Asbury Creek siphon		13,558	
Excavation, 2,041 cu. yds. at $ 0.53			
Concrete, 582 " " 19.60			
Paving, 329 " " 3.24			

Costs to December 31, 1915, of Grand Valley Project, Colorado
(*Continued*)

Jerry Creek siphon		$ 15,824
Excavation, 2,437 cu. yds. at $ 0.80		
Concrete, 700 " " 16.37		
Paving, 577 " " 4.19		
Coal Creek siphon		18,599
Excavation, 1,680 cu. yds. at $ 0.79		
Concrete, 656 " " 20.60		
Paving, 961 " " 3.91		
Division 2, Earthwork		163,267
Culverts, bridges, etc		49,261
Lewis wash siphon	$8,365	
Excavation and backfill, 730 cu. yds. at $1.27		
Concrete, 330 cu. yds. at $22.54		
Wasteway	3,732	
Excavation and backfill, 1,096 cu. yds. at $0.64		
Concrete, 130 cu. yds. at $21.57		
Machinery, 4,300 lbs. at $0.1028		
Steel flume	9,278	
Excavation and backfill, 585 cu. yds. at $0.968		
Concrete, 230 cu. yds. at $16.40		
13.5′ steel waterways, 224 lin. ft. at $14.82		
Structure, $22.85 M., BM. at $90.56		
Division 3, Earthwork		183,234
Culverts, bridges, etc		39,349
Siphon		10,244
Excavation, 1,655 cu. yds. at $ 0.52		
Backfill, 2,200 " " .20		
Concrete, 329 " " 22.20		
Paving, 301 " " 5.48		
Wasteway		3,503
Excavation, 2,435 cu. yds. at $ 0.22		
Backfill, 150 " " .60		
Concrete, 138 " " 15.88		
Gates, cast iron, 4,300 lbs. " .142		
Paving, 17 cu. yds. " 3.55		
Wasteway		5,345
Excavation, 3,950 cu. yds. at $ 0.25		
Backfill, 120 " " .42		
Concrete, 148 " " 21.20		
Gates, cast iron, 4,300 lbs. " .126		
Paving, 70 cu. yds. " 8.99		

Flume	$ 7,507	
Excavation, 1,125 cu. yds. at $ 0.76		
Concrete, 210 " " 10.15		
Lumber, 19.5 M., BM. " 77.80		
13.5′ steel waterway, 192 lin. ft. at $15.64		
Flume	8,809	
Excavation, 1,700 cu. yds. at $ 0.53		
Concrete, 226 " " 12.24		
Lumber, $22.85 M., BM. " 76.75		
13.5′ steel waterway, 224 lin. ft. at $14.73		
Paving, 40 cu. yds. at $ 2.11		
Flume	11,883	
Excavation, 5,976 cu. yds. at $ 0.217		
Concrete, 228 " " 22.72		
Lumber, $19.5 M., BM. " 85.25		
13.5′ steel waterways, 192 lin.ft. at $18.40		
Paving, 80 cu. yds. at $2.67		
Division 4, Earthwork	146,063	
Bridges and culverts	27,209	
Lateral system		$147,742
Preliminary and general	10,524	
Priming and puddling	819	
District 1, Earthwork	41,826	
Minor structures	66,750	
District 2, Earthwork	11,500	
Minor structures	16,323	
Drainage system, preliminary		1,825
Flood protection, preliminary		557
Farm units, preliminary		2,708
Permanent improvements and land		8,735
Telephone system, 43 miles at $212.80		9,149
General administrative expense		5,272
Total		$2,659,025

The Grand Valley Project was constructed and in the main designed by Mr. J. H. Miner, under the general direction of Mr. R. F. Walter, Supervising Engineer.

CHAPTER VI

UNCOMPAHGRE PROJECT

DESCRIPTION

The Uncompahgre Valley lies on the western slope of the main range of the Rocky Mountains in western Colorado. Its drainage area of 500 square miles is tributary to the Gunnison River, which it joins a short distance below Delta, Colo.

The Uncompahgre River was early diverted for the irrigation of its immediate valley by means of small canals on both sides of the river.

As in many other Western valleys, the development of irrigated lands proceeded under the stimulus of seasons of plentiful water supply and the usual optimistic tendencies, until it was far past the point of safety, and most of the canals were frequently without water in the late summer, though well supplied in May and June; and in years of low water supply, all except the very oldest were short. This condition led to heavy losses and much litigation.

To relieve this situation and irrigate the remaining unwatered lands of the Valley, the United States has undertaken to bring into the valley the water of Gunnison River, which flows in a deep canyon to the eastward, roughly parallel to the Uncompahgre. This requires a tunnel about 30,580 feet in length, and a canal at its west portal to carry the water to the head of the valley and make it available to all the canals. Later, as plans and construction progressed, it was found necessary to acquire or build an entire canal and lateral system.

GUNNISON TUNNEL

The tunnel is nearly square in cross-section with an arched roof. It is 11 feet wide in the clear, and has a height of 10 feet to the spring of the arch. It is built on a grade of .002 and has

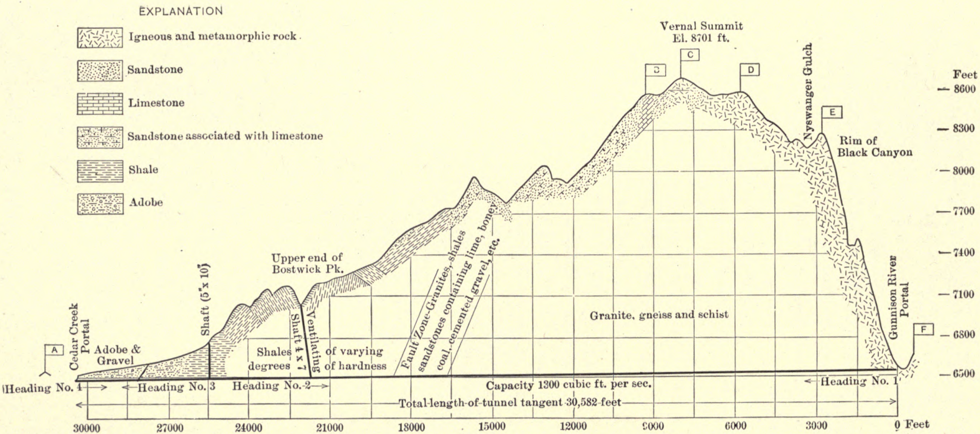


FIG. 22.—Profile of Gunnison Tunnel, Uncompahgre Valley, Colorado.

a theoretical velocity of about 10 feet per second when running full capacity, which is about 1,000 cubic feet per second.

The west portal of the tunnel is in the valley of Cedar Creek, which has a slope of about 2½ per cent, and the cut approaching the tunnel is 1,900 feet long. The western 1,300 feet of the tunnel in the alluvial bottom of Cedar Creek yielded large quantities of water, required heavy timbering, and was very hazardous work.

The construction of this tunnel was let by contract and work was started in February, 1905. The contractor was insufficiently supplied with capital and unable to install adequate equipment, and within four months he went into bankruptcy and the work was prosecuted thereafter by Government forces.

The work on the tunnel was carried on from four headings: Heading No. 1 began at the river portal and progressed westward from Gunnison River. Heading No. 2 was driven eastward toward the Gunnison River from a shaft located 950 feet from the west portal. Heading No. 3 was driven from the same shaft toward the west portal, and Heading No. 4 was driven eastward from the western portal. A heavy cut about 50 feet deep continued the conduit from the west portal of the tunnel to grade in the valley of Cedar Creek, a distance of about 1,900 feet.

The work from Heading No. 1 was in hard crystalline rock, some of it so hard as to present great difficulty to drilling, and most of it standing without timbering. Occasional seamy and broken sections, aggregating about 20 per cent, required timbering, and water was encountered frequently in these seams, growing worse and more profuse as the work advanced. The grade of the tunnel being from the portal toward the heading made it necessary to pump from the heading to the river all the water that leaked into the tunnel. At times the flow increased to such an extent as to stop the work. Frequently the pressure of water encountered in the drill holes was sufficient to eject the charge before it could be exploded. It was necessary to increase the pumping capacity and to provide discharge pipe line 12 inches in diameter. On this heading a record of 449 linear feet was established in January, 1908.

Heading No. 2 was mostly in hard blue shale. Much of this was of such character as to stand temporarily without timbering and required only light timbering to prevent sloughing of the

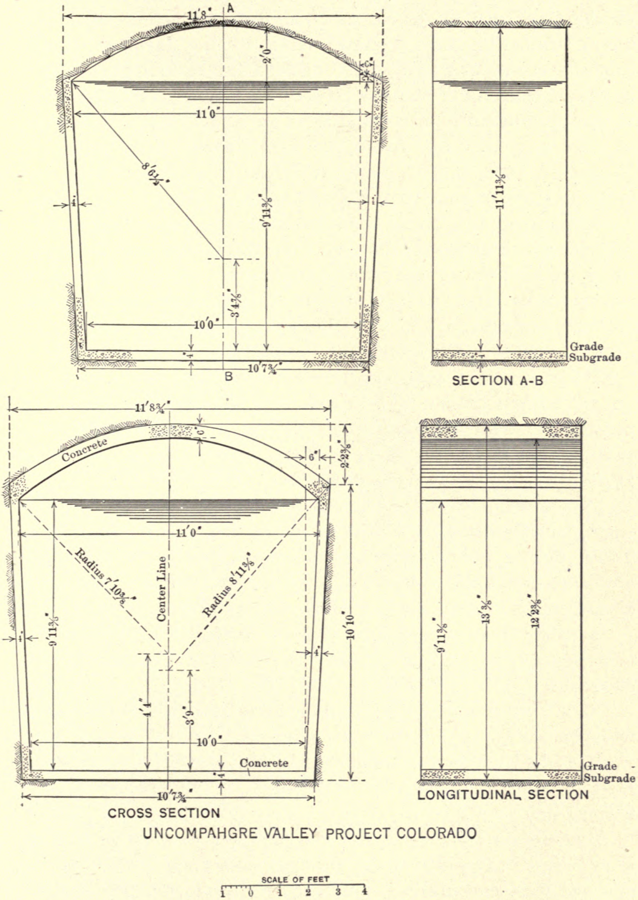


FIG. 23.—Gunnison Tunnel. Sections in Rock.

sides and roof. The material, however, became softer and full of shells to such an extent as to destroy its cohesiveness and heavy timbering was required close to the heading. Large quantities of water were also encountered and the humidity caused continual slacking of the lime, which, with other causes, resulted in the production of a large amount of heat. The combination of heat and humidity made the work extremely difficult. In December, 1906, this heading was driven to a geologic fault and a flow of water of more than 1,000,000 gallons per hour was tapped. Accompanying this water was an enormous volume of carbon dioxide, which drove all the men from the tunnel and compelled the abandonment of the work temporarily. After about three weeks, the heading was regained, but the flow of gas was so strong and the temperature was so high that work was impossible. To overcome this difficulty, it was decided to sink a shaft about 9,000 feet from the west portal of the tunnel 700 feet in depth as an aid to ventilation. The excessive humidity, the high temperature, and the swelling ground so rotted and weakened the timbers that it was necessary to start concrete lining at once to avoid extensive replacement of timbers.

The presence of water necessitated the elevation of the tram track, and deprived the workmen of the use of the tunnel floor. Tools, dinner pails, explosives, repair parts, and every other appliance used in the tunnel had to be kept on shelves or platforms or suspended in some manner above the water.

A steady flow of 7½ cubic feet per second was encountered continuously, which was increased whenever a new spring was encountered.

Notwithstanding the great difficulties and delays connected with this work, parts of the work where the difficulties were least were finished with great rapidity. In March, 1906, a single gang made progress on excavation of 809 feet, or an average of 25.6 feet per day.

Progress on Heading No. 3 was very satisfactory as long as it remained in the blue shale, although occasional flows of water and gas were encountered, but when the shale was left behind the ground became exceedingly difficult, consisting of adobe mud, gravel pits, sand beds, or some mixture of these materials. The same description applies to the material encountered from Heading No. 4, which was extremely difficult, requiring heavy timbering

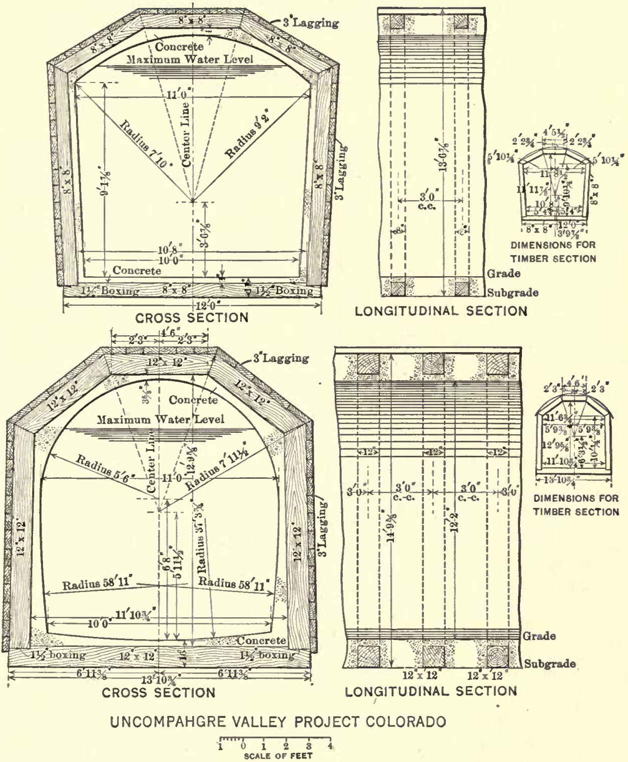


FIG. 24.—Sections of Tunnel. Sections in Shale and Gravel.

close to the heading and causing great hazard to men and equipment.

The tunnel was finally excavated through in January, 1910, the progress being shown in the following table:

	1905	1906	1907	1908	1909	1910	Total
Full Section:							ft.
Earth and gravel	1,956	1,066	....	....	....	....	3,022
Shale	3,154	5,146	....	....	....	....	8,300
Gravel and shale	....	660	....	....	....	....	660
Sandstone	....	304	1,264	....	....	....	1,568
Granite and schist	477	3,181	1,527	200	....	....	5,385
Total	5,587	10,357	2,791	200	....	....	18,935
Undercut drift, 11 x 8 feet:							
Granite and schist	1,691	.....	2,257	4,077	3,478	....	11,503
Sandstone	....	.....	207	....	....	....	207
Total	1,691	.....	2,464	4,077	3,478	....	11,710
Enlargement:							
Granite and schist	1,691	.....	....	....	8,105	1,707	11,503
Sandstone	....	.....	....	....	207	....	207
Total	1,691	.....	....	....	8,312	1,707	11,710

The rapid decay of the timber in the tunnel due to heat and humidity and the tendency of the shale to swell and bulge the timbers made it necessary to begin the concreting in October, 1906, and continue steadily thereafter.

The concreting plant at the west end consisted of a rotary mixer, placed on a platform near the bottom of the working shaft, just high enough to allow cars to pass under it.

The sand and gravel were obtained from a hill about a mile away, and, after screening, were dumped into chutes leading down the shaft into measuring bins which discharged directly into the mixer, from which the cars were filled and hauled to the concreting place. The mixture used was 1:3:6.

The floor of the tunnel was first laid direct from the cars. Timber forms were then placed for the side walls, fastened to the tunnel timbers by means of wires.

In placing concrete in the sides and roof a traveller was used, which consisted of a platform mounted on a frame which raised it to such a height as to permit cars to pass under it, the frame

being on wheels running outside the tramway. On this traveller was a hoist in line with the tram track, which pulled the cars up the traveller where the concrete was dumped on the platform, remixed in boxes, and shovelled into place. As the work progressed the traveller was moved ahead and the process repeated.

At the east end of the tunnel no traveller was used, the concrete being shovelled into boxes placed on platforms where it

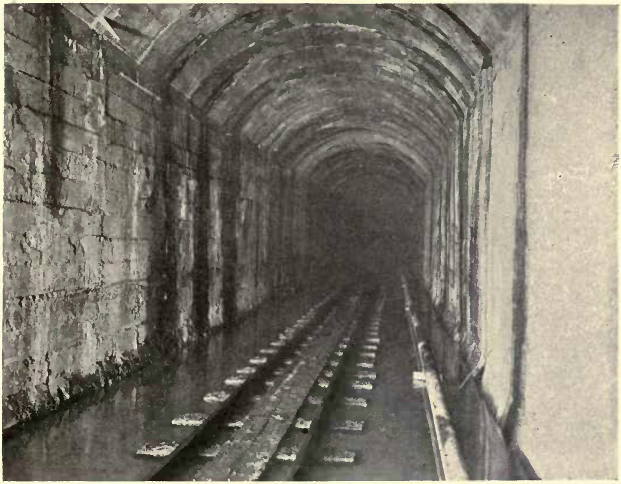


Fig. 25.—Interior Gunnison Tunnel.

was remixed and shovelled into the forms. The mixture here was crushed rock, from the tunnel dump, and the smaller parts of which were mixed with the sand of the river, which was very fine, requiring the coarser screenings to make the proper gradations.

Such parts of the tunnel as required lining for support were lined with a heavy wall of concrete, 12 inches thick, the overbreakage being filled with rock spauls carefully built in place.

This heavy lining was provided for the entire length of aluvium under Cedar Creek, all of the shale section, and the broken rock through the geological fault. It also included a considerable part of the work driven from Heading No. 1, which was all in

granite or schist, but lining was necessary in many places where the rock was broken or seamy.

Those parts solid enough to stand without timbering have not been lined, but will be lined on the bottom and sides with a thin coat of concrete at some future time when it becomes necessary to employ the tunnel to its full capacity.

The electric railway, which had been used to transport supplies and equipment into the tunnel and hauling out the excavated material, was set permanently in the concrete bottom of the tunnel and is, therefore, available for inspection and repairs whenever the water is drawn out of the tunnel.

DIVERSION DAM

A diversion dam has been provided in the Gunnison River to divert the river into the Gunnison Tunnel. It is a rock-filled crib structure, with a crest 240 feet long and 18 feet wide, and an apron 42 feet wide. In front of the intake gates a sluiceway has been provided to prevent the accumulation of gravel. This is provided with two cast-iron sluice-gates, each 6 by 8 feet, operated by hand.

CANAL SYSTEMS

South Canal.—The South Canal has a capacity of 1,000 second-feet, is 11½ miles in length, and extends from the west portal of Gunnison Tunnel to the Uncompahgre River, about 9 miles southeast of Montrose, Colo. Thirteen thousand six hundred acres are irrigated from this canal.

Beginning at the end of the portal cut, the dimensions, distances, and facing materials of the South Canal are as follows: A concrete-lined chute ending in a vertical drop of 10 feet and given a total fall of 30 feet in 520 feet; concrete-lined canal with bottom width of 25 feet, depth of 4.5 feet, side slopes of 1 to 1, including two vertical drops each of 11.55 feet fall; earth canal with bottom width of 30 feet, depth of 10 feet, side slopes of 2 to 1, extending 1½ miles; a concrete-lined section with bottom width of 6.3 feet, depth of 8.45 feet, and side slopes of 1 to 1, extending through a 40-foot cut and ending in two 8.17-foot drops; an earth section with bottom width of 30 feet, depth of 10 feet, and side slopes of 2 to 1, extending nearly ½ mile to mile 2; an inclined-concrete chute with a fall of 46 feet in 350

COST OF GUNNISON TUNNEL AND HEAD-WORKS

666 Y	Lin. Feet	Cubic Yards	Labor	Material	Engineering	Total	Unit Costs per Unit: Labor	Mat'l	Engr.	Total
Head-works—Excavation	....	5,806	10,235.69	5,113.97	470.48	15,820.14	1.76	0.88	0.08	2.73
Concreting	....	327	2,643.64	2,809.06	12.76	5,465.46	8.09	8.59	0.04	16.71
Placing gates	....	.....	581.53	1,110.96	15.00	1,707.49	......	.....	....	......
Gunnison Tunnel—Complete except concrete										
Excavation Heading No. 1	7,080	.....	352,675.71	187,020.36	12,050.20	551,746.27	49.81	26.42	1.71	77.93
Excavation Heading No. 2	8,604	.....	369,975.87	162,787.45	5,431.74	538,195 06	43.00	18.92	0.63	62.55
Excavation Heading No. 3	1,696	.....	55,492.41	27,930.61	834.66	84,257.68	32.72	16.47	0.49	49.68
Excavation Heading No. 4	3,246	.....	134,768.54	79,122.51	7,209.39	221,100.44	41.52	24.38	2.22	68.11
Undercut Drift, Excavation Heading No. 1	3,799	.....	144,386.96	125,126.82	3,371.39	272,885.17	38.01	32.94	0.89	71.83
Excavation Heading No. 2	6,220	.....	244,471.14	139,183.49	4,464.42	388,119.05	39.30	22.38	0.72	62.40
Enlarging Undercut Drift, Excavation Heading No. 1	3,799	.....	80,078.38	30,038.19	1,111.98	111,228.55	21.08	7.91	0.29	29.28
Excavation Heading No. 2	6,220	.....	116,825.79	32,958.60	1,979.93	151,764.32	18.78	5.30	0.32	24.40
Shafts, Ventilating Shaft	679	.....	12,736.38	4,489.79	....	17,226.17	18.76	6.61	....	25.37
Working Shaft	264	.....	4,871.26	901.30	....	5,772.56	18.45	3.41	....	21.86
Concreting Heading No. 1, Complete section	2,007	.....	32,951.51	19,210.44	561.25	52,723.20	16.42	9.57	0.28	26.27
Floor and walls	34	.....	243.64	122.83	3.12	369.59	7.17	3.61	0.09	10.87
Floor	8,097	.....	14,544.06	9,108.85	255.00	23,907.91	1.80	1.13	0.03	2.95
Concreting Heading No. 2, Complete section	9,780	.....	113,300.56	77,179.96	1,420.00	191,900.52	11.59	7.89	0.15	19.62
Floor	5,044	.....	9,562.97	5,917.95	111.19	15,592.11	1.90	1.17	0.02	3.09
Concreting Heading No. 3, Complete section	1,696	.....	13,318.33	11,168.65	197.80	24,684.78	7.85	6.59	0.12	14.55
Concreting Heading No. 4, Complete section	3,246	.....	27,273.64	23,458.68	377.30	51,109.62	8.40	7.23	0.12	15.75
Portal Cut—Excavation Class 1	....	31,934	10,504.36	4,053.11	204.70	13,762.17	0.33	0.10	0.01	0.44
Excavation Class 2	....	69,989	27,231.92	10,546.05	637.64	38,415.61	0.39	0.15	0.01	0.55
Excavation Class 4	....	33,185	39,470.50	15,968.62	969.14	56,408.26	1.19	0.48	0.03	1.70
Concreting	....	2,023	16,477.97	14,749.26	249.68	31,476.91	8.15	7.29	0.12	15.56
West Portal of Tunnel—Excavation	....	330	523.67	2.57	....	526.24	1.59	0.01	....	1.60
Concreting	....	165	994.19	564.97	30.00	1,589.16	6.03	3.42	0.18	9.63
Tunnel Road—Maintenance	9.86 mils.		12,593.47	233.37	....	12,826.84	1,277.23	23.67	....	1,300.90
Construction	....	30,000	13,618.86	6,588.88	....	20,207.74	0.45	0.22	....	0.67
Surveys	....	.....	4,518.35	....	....	4,518.35	......	.....	....	......
Grand Total			1,866,871.30	997,467.30	41,968.77	2,905,307.37				

feet; a concrete-lined canal with bottom width of 8 feet, depth of $8\frac{1}{2}$ feet, and side slopes of $\frac{1}{2}$ to 1, extending 1.5 miles through deep cuts and along steep hillsides and including three concrete-lined tunnels 10 feet square and aggregating 1,877 feet in length;

FIG. 26.—West Portal of Gunnison Tunnel.

a concrete-lined section with a bottom width of 25 feet and containing seven vertical drops with a total fall of 68 feet in 2,430 feet; a concrete-lined section with bottom width of 13 feet, depth of 6.4 feet, and side slopes of $\frac{1}{2}$ to 1, extending half a mile; an earth section with bottom width of 30 feet, depth of 10 feet, and side slopes of 2 to 1, extending, with the exception of a concrete-lined 35-foot cut, to a short distance beyond mile 8; a concrete-lined canal, 13 feet in bottom width, passing through a 40-foot cut; a short section of earth canal; tunnel No. 4, 396 feet in length, a concrete-lined canal 8 feet in bottom width, extending 500 feet; a 352-foot wooden flume across an arroyo; tunnel No. 5, 390 feet in length; a short length of concrete-lined canal 8 feet in bottom width; an inclined chute with a fall of

Fig. 27.—Concrete Chute in South Canal, Uncompahgre Project.

25 feet in 260 feet; a concrete-lined canal 13 feet in bottom width, extending a third of a mile; an earth canal with a bottom width of 40 feet, depth of 8.3 feet, and side slopes of 2 to 1, extending $2\frac{1}{2}$ miles and ending in a timber crib outlet structure discharging into the channel of Uncompahgre River.

At several points along the South Canal trouble has been experienced by the disintegration of concrete under the action of the alkali. This occurs mainly on canal lining, culverts, and other points where small masses of concrete are in such contact with ground water heavily laden with salts as to permit the water to percolate through the concrete and evaporate on the other side, thus leaving the salt crystals inside the concrete, where its expansive power gradually disintegrates the side on which the evaporation takes place, gradually reducing the whole to the consistency of mortar. This does not occur everywhere, nor anywhere uniformly, but throughout the Valley there are spots here and there where this action takes place. For this reason, many head-works and other structures have been built of wood where otherwise concrete might have been employed. The damage to the South Canal from this cause to date is estimated at between $30,000 and $40,000.

SETTLEMENT OF SHALE FOUNDATIONS

In several localities on the Uncompahgre Valley Project, Colorado, where concrete-lined canals have been constructed through shale, trouble has been caused by settlement of the lining, causing cracks, increased seepage, and accelerated disintegration of the concrete due to alkali action.

The settlement of the lining and drops on the South Canal appear to be due to water penetrating the indurated shale on which structures are founded, and removing a portion of the soluble salts from the seams of the shale. In many places this settlement amounts to from 6 to 12 inches. Any settlement, however slight, ruptures the concrete and allows more water to escape into the shale with the result that the alkali is removed faster and the settlement accelerated.

Where the piers are founded on sandy loam, or adobe soils, there is no settlement even when saturated, unless whole areas settle, as has happened in several instances, due to irrigation or

Fig. 28.—Lined Section South Canal, Uncompahgre Valley, Colorado.

to seep water. Where piers are located on shale, they invariably settle if the ground becomes wet, but in the case of metallic flumes, it is comparatively easy to keep the foundation dry.

The tunnel approaches on the Selig Tunnel have settled several inches, which has caused a few cracks. These approaches are in shale and settlement is due to the leaching out of soluble salts.

In many places where canals are constructed through hard shale requiring powder to loosen, they have settled badly when water was turned through them. In a few instances, the shale has swelled, at first causing the bottom to bulge.

Private Canals.—In the length of the valley, about 30 miles, the river falls over 1,200 feet, or about 40 feet to the mile. This makes a condition where diversion of the waters of the river is comparatively easy and a large number of small canals were built by private enterprise to command the bottom-lands along the river, and several larger canals were constructed to carry water to the higher bench lands further away, and in general with better soil.

In that portion of the Uncompahgre Valley covered by the works of the Reclamation Service there are 110 canals and laterals having an aggregate length of nearly 500 miles, constructed by private enterprise. Most of these have been acquired by the Reclamation Service under a general comprehensive plan for the unification of the irrigation work of the valley. The existing works were only adapted to the new system to a very small extent, most of them requiring enlargement or entire replacement.

The highest irrigation in the project is from turnouts taken directly from the South Canal. At the point where this canal reaches the Uncompahgre River, a siphon 24 inches in diameter and 1,100 feet in length has been provided to carry across the river the water needed by the West Canal, which is a new canal built by the Reclamation Service to water lands higher than covered by the Montrose and Delta Canal, which heads a short distance below. The latter canal was acquired by the Reclamation Service, enlarged and extended and new head-works built, which include a sluicing basin and sluice-gates to dispose of gravel washed into the heading by the floods of the Uncompahgre River.

The Montrose and Delta Canal diverts water from Uncompahgre River about 2 miles below the mouth of the South Canal, and carries water to Spring Creek Mesa, dropping its water 120

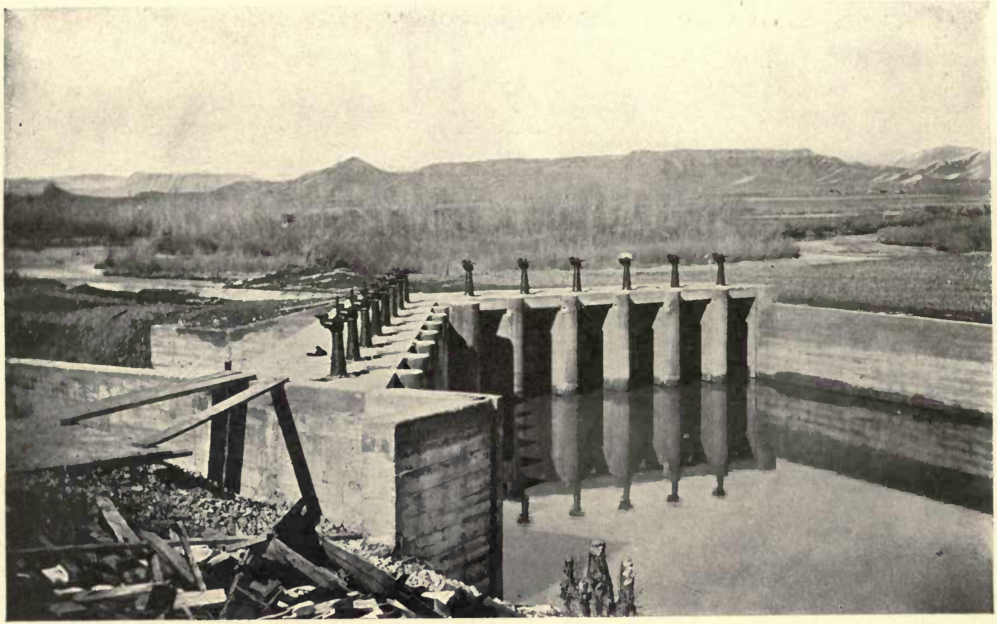


FIG. 29.—Head-works Montrose and Delta Canal, looking downstream, Uncompahgre Project.

FIG. 30.—Happy Canyon Flume, Uncompahgre Project.

feet into Coal Creek Canyon about the thirty-first mile. The water is diverted from Coal Creek 5 miles below the drop to water lands further down. This system was constructed in 1883 to 1886, and was acquired by the United States in 1908 and enlarged to a capacity of 450 cubic feet per second, or about double its former size. The laterals were also enlarged and extended to cover about 33,600 acres of land in all.

The head-works of this canal when acquired, as well as most of the other structures, were of wood in an advanced stage of decay. The head-works were rebuilt of concrete and provided with a sluiceway for ridding the water of its load of gravel when in flood.

Several wooden flumes were also replaced by steel flumes on concrete pedestals.

Iron Pressure Pipe.—In the extension of the Montrose and Delta system, in order to reach a portion of the irrigable area, it became necessary to carry about 42 cubic feet of water per second across a depression 3,800 feet wide in which the maximum depth was about 200 feet.

The depression to be crossed contained a large amount of alkali, for which reason, as well as the high cost and high head, reinforced concrete was not considered suitable. After considering everything, the decision was reached to use commercially "pure iron" as being more resistant to alkali action than steel, and under the conditions present more permanent than wood.

The contract specifications for the iron required a tensile strength not less than 48,000 nor more than 52,000 pounds per square inch and elastic limit not less than 35,000 pounds. They imposed limits of carbon, .01 per cent; manganese, .02 per cent; phosphorus, .005 per cent; sulphur, .02 per cent; oxygen, .03 per cent; and silicon, trace. The contractor was unable to secure the specified elastic limit with this composition, and the required strength of pipe was achieved by increasing the thickness 25 per cent.

The gasket used was of asbestos saturated with a mixture of red lead and raw linseed oil. There were two layers of asbestos reinforced with fine copper wire, the finished gasket being $^3/_{16}$ inch thick.

The Loutzenhizer Canal was originally built in 1883, with a capacity of 86 second-feet by O. D. Loutzenhizer, and was ac-

quired in 1908 by the United States, and enlarged to a capacity of 290 cubic feet per second, and the laterals from it were enlarged and extended to cover about 11,200 acres of land.

The California Ironstone Canal on the west side of the river was built with a capacity of about 130 cubic feet per second, and

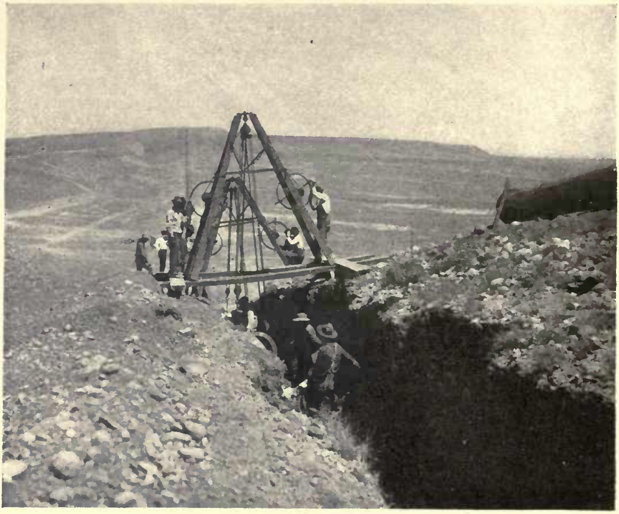


FIG. 31.—Laying High Mesa Pressure Pipe, Uncompahgre Project.

in 1913 watered 2,332 acres of land. It has been acquired by the United States for enlargement to 350 second-feet, for the irrigation of 26,000 acres.

The United States has also acquired and enlarged the Selig Canal to a capacity of 300 cubic feet per second and extended it to additional acreage, aggregating 22,400 acres, all on the east side of the Uncompahgre River. It heads 2 miles northwest of Montrose, with a collapsible weir-frame dam, and timber head-works, supported on piles.

The East Canal has timber head-works and a portion of its alignment is near or upon that of the old Colorow Canal above

Olathe. It has a capacity of 325 cubic feet per second at the head, and delivers water to 22,000 acres. A prominent feature of the distribution system of this canal is the Garnet Mesa siphon, which delivers 25 second-feet of water to about 1,825 acres on Garnet Mesa through a wood-stave pressure pipe 8,560 feet long, under a maximum head of 90 feet.

Taylor Park Reservoir.—The Uncompahgre and Gunnison rivers are fed by melting snows, and begin to rise when the snow begins to melt in the spring, reaching culmination some-

SUMMARY OF COSTS OF GARNET MESA SIPHON

Services	Surveys	Excavation	Building	Total
Foremen	......	$234.67	....	$234.67
Engineering	$281.21	176.21	$302.17	759.59
Clerical	......	14.00	....	14.00
Labor	6.14	......	....	6.14
Hauling material and supplies	.17	45.24	34.13	79.54
Horses	38.32	15.97	2.90	57.19
Contract payments	......	3,798.27	11,297.38	15,095.65
Hauling siphon pipe	......	......	388.29	388.29
Camp maintenance	......	13.16	....	13.16
Puddling	......	653.38	....	653.38
Excavating	......	1,884.40	....	1,884.40
Recording right of way	......	1.45	....	1.45
Creosoting	......	1.25	....	1.25
Miscellaneous	......	33.26	14.75	48.01
Total services	$325.84	$6,871.26	$12,039.62	$19,236.72
Supplies				
General	$2.20	$4.64	$526.22	$533.06
Tools	.97	25.28	.47	26.72
Hardware	1.20	1.37	518.36	520.93
Lumber	6.48	2.39	1,710.34	1,719.21
Depreciation	2.14	......	.71	2.85
Repairs to equipment	......	4.68	4.28	8.96
Explosives	......	.82	....	.82
Travel	......	17.22	....	17.22
Creosote	......	......	93.92	93.92
Forage	......	......	3.97	3.97
Total supplies	$12.99	$56.40	$2,858.27	$2,927.66
General				
Storehouse charges	$1.66	......	....	$1.66
Overhead charges	48.59	$419.33	$490.95	958.87
Total general	$50.25	$419.33	$490.95	$960.53
Grand total	$389.08	$7,346.99	$15,388.84	$23,124.91

Colorado—Uncompahgre Project Costs to December 31, 1914

Summary

Item No.	Feature	Total Cost	Per Cent Completed Force Acct.	Per Cent Completed by Contract	Per Cent of Completion
1	Gunnison Tunnel and Diversion	$2,905,307.37	99	1	93
2	South Canal System..........	836,532.11	30	70	96
3	Montrose and Delta..........	394,208.60	99	1	90
4	Other canal systems..........	847,734.64	64	36	62
5	Drainage system..............	803.07	100	0	1
6	Power system	262.50	100	0	100
7	Real estate	145,724.63	100	0	39
8	Buildings	16,274.62	69	31	81
9	Telephone line	6,507.28	9	91	39
10	Farm unit subdivision........	3,555.28	100	0	15
11	Preliminary investigations.....	63,445.61	100	0	100
12	General administration	242,055.58	100	0	100
13	Operation and maintenance during construction.........	368,644.36	100	0	83
	Total.............	$5,831,055.65	83	17	63

time in June, and then declining irregularly until winter. The maximum demand for irrigation is usually later than the maximum flow of the streams, and does not decline so rapidly. The combined flow of both streams available for irrigation in the Uncompahgre Valley is usually sufficient for the requirements of the area to be included in the completed project, though sometimes there would be a slight shortage in August or September. One year in the history, however, the year 1902, a phenomenally dry year, there would have been according to the record a shortage of over 40 per cent.

It may be that in future it will be desirable to provide storage for this project. With this possibility in view studies have been made of a reservoir site on Taylor River, a tributary of the Gunnison, having a drainage area above the reservoir site of 253 square miles.

A masonry dam has been designed for construction in the gorge at the lower end of Taylor Park, which would be about 150 feet above river-bed, arched in plan, and would store 106,000 acre-feet of water, costing $15 or $16 per acre-foot.

Such a reservoir would obviate deficiencies for the future

unless a year as low as 1902 should again occur, in which case the shortage, although much reduced, would not be entirely prevented.

The Gunnison Tunnel and South Canal were constructed by Mr. I. W. McConnell, under the general direction of J. H. Quinton, Supervising Engineer. The designs were approved by Mr. Geo. Y. Wisner and W. H. Sanders, Consulting Engineers.

CHAPTER VII

BOISE PROJECT

DESCRIPTION

The Boise River is a tributary of Snake River, and drains an area of 2,650 square miles on the Western slope of the Sawtooth range of mountains, above the point where it leaves the mountains, and about 1,000 square miles more of foothill and valley area.

It receives most of its water supply from the melting of snow in the mountains, and hence has a variation of discharge characteristic of such conditions, namely, a low stage in the winter while the mountain streams are frozen, a rising stage with the progress of spring, reaching a culmination sometime in June, and declining during July and August as the snows disappear, reaching a minimum again in winter. The regularity of this program is at times interrupted by rainfall and fluctuations of temperature, but such streams are far more regular and dependable than those depending mainly upon rainfall for their supply. On such streams the full utilization of the water supply for irrigation requires the storage of the winter flow and the excess flow of May and June, for use during July, August, September and October, and may require a storage capacity of about one-half the total amount of water used in irrigation, the other half being drawn from the natural flow without storage.

The Boise project is one of the largest undertaken by the Reclamation Service. It provides for the storage of the waters of Boise River at Arrow Rock and at Deer Flat, and their use upon over 200,000 acres in the Boise Valley. The Deer Flat Reservoir has been completed by the construction of one small, and two large, earthen embankments containing an aggregate of 2,320,000 cubic yards. The reservoir covers 9,250 acres and has an available capacity above outlets of 173,000 acre-feet. Water was delivered for irrigation from this reservoir in 1911. It is filled by a long feed canal heading in the Boise River above

Barberton, about 8 miles above the city of Boise. The lateral system has been completed for 120,000 acres of new land. Altogether 580 miles of canal have been built by the Government, and the complete project will have over 700 miles of canals.

BOISE DIVERSION DAM

The diversion dam on the Boise River is built of random rubble basalt laid in portland cement concrete, with the faces of selected stones laid with some regularity.

The length of the masonry portion of dam is 386 feet, and core walls extend into the hills nearly 200 feet more. Its height from lowest foundation to top of abutment walls is about 68 feet. It raises the low-water stage 34 feet. It is founded on gravel and boulders, and has an ogee overflow spillway section 216 feet in length, and a logway 30 feet wide, 4 feet lower than the main spillway from which it is separated by a wall 4 feet thick and 7 feet high. A fish ladder is also provided next to the logway. At the lower toe of the dam is provided an apron of rock-filled crib-work, decked with 4-inch lumber, founded 13 feet below the bed of the river. This extends down-stream 50 feet beyond the masonry toe. (Fifth A. R., P. 124.)

A bank of sand and gravel on a slope of 3 to 1 and reaching about two-thirds of the height was provided on the up-stream side. The entire pond has since been filled with sand deposited by the river since construction.

For the diversion of the river during construction, two parallel tunnels were provided in the left bank, each 6 × 8 feet, closed by cast-iron gates. These tunnels are 160 feet long and are lined with concrete, and more recently a third tunnel has been built parallel to the other two, and all are used as tail-races in the development of power, and the power-house built over them. They are now controlled by butterfly gates, each 9 × 12 feet, protected by a grillage in front.

To the south of the power-house are the head-works of the main canal, consisting of a set of eight cast-iron gates, each 5 × 9 feet, operated by hand.

The logway is closed by a roller dam of 30 feet span, and a chord length of 8 feet. This type of closure was selected as one that could be closed with little leakage, requires but one span,

permits overflow during floods, and can be raised high enough to be entirely clear of the water surface to permit the passage of logs and drift without danger. It was found also that it could be installed cheaper than any other type considered. The device designed for this purpose consists of a small cylinder of 1 foot 3¾ inches radius, to which is attached by suitable bracing the dam proper, a cross-section of which is an arc of a circle with a 6-foot radius and having a chord length of 8 feet. The center of curvature of this arc is 4 feet down-stream from the center of the small cylinder or shaft, and about 9 inches below it when the dam is closed. At each end it has a gear engaging a rack laid on inclined abutments, and by means of a sprocket chain wrapped around one end of the cylinder and connecting with the operating mechanism the dam is rolled up the abutments to open it, and rolled down to close the opening. The racks are laid on an angle of 21½ degrees with the vertical.

The inside faces of the concrete piers forming the abutments converge slightly up-stream, and at each end of the dam is a flexible plate bound with oak timbers which spring against the abutments as the dam is being closed, thus making it practically watertight at the ends. An oak sill, attached to the bottom of the dam proper, rests on the crest of the logway when the dam is closed to secure water-tightness at the bottom. An inclined timber facing, tangent to the cylindrical shaft, extends down-stream from the crest of the dam so that water and débris may pass over the structure without injuring it. When the dam is open it leaves a clearance above the logway of about 18 feet. The controlling mechanism is operated by a direct-connected motor of 3 horsepower at 500 r.p.m., but hand control is also arranged for use in case of trouble with the motor. Fifteen to twenty minutes are required to fully open the dam with the motor.

Cost of Rolling Dam

Preparatory expense (including installation and removal of coffer-dam)	$ 802.18
Transportation of laborers	327.57
Cutting and facing old concrete	1,593.95
Placing concrete	1,271.16
Rolling dam and accessories, f. o. b. Boise	2,307.34
Installation	1,105.94
Purchase and installation of motor	122.50
Total	$7,530.64

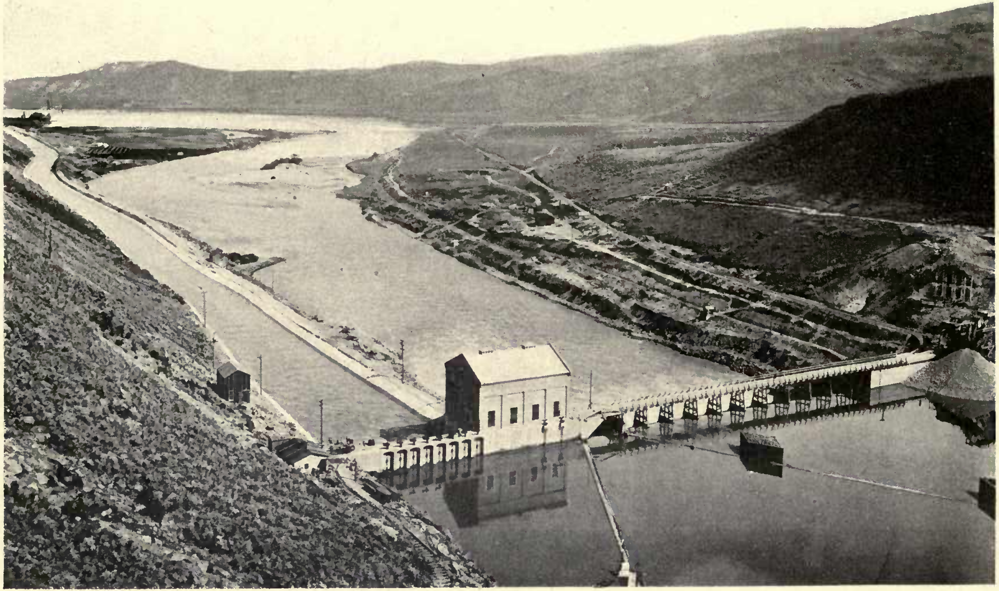


FIG. 32.—Power Plant and Head-works, Boise Main Canal.

BOISE MAIN CANAL

The main canal has a capacity of about 2,700 cubic feet per second and will carry water for the direct irrigation of about 160,000 acres of desert land and also will be used as a feed canal to carry water to the Deer Flat Reservoir about four miles southwest of Nampa. Through much of its length, it is located on the alignment of the old New York Canal, the right of way of which was utilized. About 25 miles from its head the canal reaches Indian Creek into which most of the water is dropped, and diverted 7 miles below, whence the canal extends about 8 miles further to the Deer Flat Reservoir.

Where the canal is dropped into Indian Creek, a lateral, called the "Mora High Line," is continued southward on the higher grade of the canal to water such land as it can reach. Above this point there are five turnouts, each constructed of concrete.

Along the same parts of the canal were located three combined culverts and wasteways at Five-mile, Eight-mile, and Ten-mile Creeks, respectively. About five miles before reaching Indian Creek the canal passes the Hubbard Reservoir, which had been built by private capital years before, and filled from the New York Canal. Its nominal capacity was about 4,000 acre-feet, but it was constructed in a locality of fissures and cavities in the natural rock, and the losses of water were so great that it was a practical failure as a storage reservoir. It was purchased by the Government for use as a wasteway to permit the quick discharge of waters of the canal in case of a break, and the water can be used from this reservoir during repairs to the canal. Its purchase effected a considerable saving over the cost of a wasteway to the river, besides saving the water turned out.

The diversion from Indian Creek into the lower division of the canal is effected by a concrete diverting-weir with a waste-gate in it. The diversion is made through six cast-iron slide gates, each 4 × 6 feet, operated by hand. The concrete was mixed in the proportions 1:4:6, and crushed rock was used for the coarse aggregate.

The Boise Main Canal was originally designed to have a bottom width of 70 feet, side slopes of 1½ to 1, bank heights 12 feet above the bottom of the canal, water depth 8 feet, and a grade of .00025 for the first 18,000 feet and .00032 below that point.

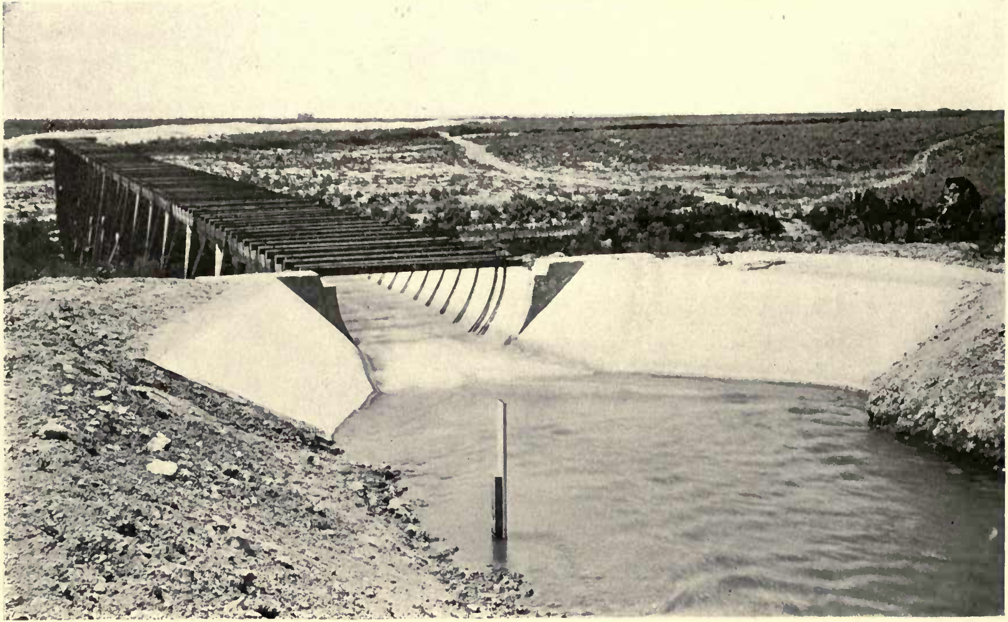


FIG. 33.—Steel Flume, Crossing Eight Mile Creek, Boise Valley, Idaho.

The location at the diversion dam, and for some distance below, is on a steep side hill formed by a talus slope of a basalt plateau containing a considerable percentage of loose rock.

Below the canyon the valley consists of a series of benches or mesas sloping to the west, which the canal is designed to irrigate. In reaching the tops of these benches, it is necessary to locate the canal upon a steep side hill for a large portion of the distance down the valley.

The demands of irrigation and the limitation of funds required the excavation of this canal at part capacity at first, having a base width of 40 feet.

When it became necessary to enlarge the canal to its final capacity of 2,700 cubic feet per second, it was found that in many of the sections where the location was upon steep ground or in hard material it would be more economical to line the canal with concrete instead of enlarging it. It was necessary to do this work between the close of the irrigation season and the cold weather.

The lining at the head-gates was carried to a point 11.5 feet above the bottom of the canal to protect it from wave action. This was gradually stepped down to a height of 9.5 feet. The concrete is 4 inches thick and is provided with expansion joints at 16-foot intervals transverse to the canal prism, and with longitudinal joints in lines parallel to the canal center line. These joints were placed halfway up the side slopes and 13 feet 4 inches from the toe of the slopes.

Transition sections 100 feet long are provided from the concrete-lined stretches to the earth stretches of the canal, and at the beginning and ends of each lined stretch cut-off walls 1 foot thick and 2 feet deep were installed.

Extensive smoothing and rectification of the banks and bottom of the canal were necessary and the banks were carefully graded with pick and shovel and thoroughly tamped to secure solid foundations for the concrete.

Concrete was laid in the bottom of the canal from each side, leaving an 8-foot roadway in the center of the canal for transporting material. The slopes were then paved and lastly the center portion, or roadway, was paved.

Most of this lining has now been in service for from five to six years and there has been no apparent deterioration except in a

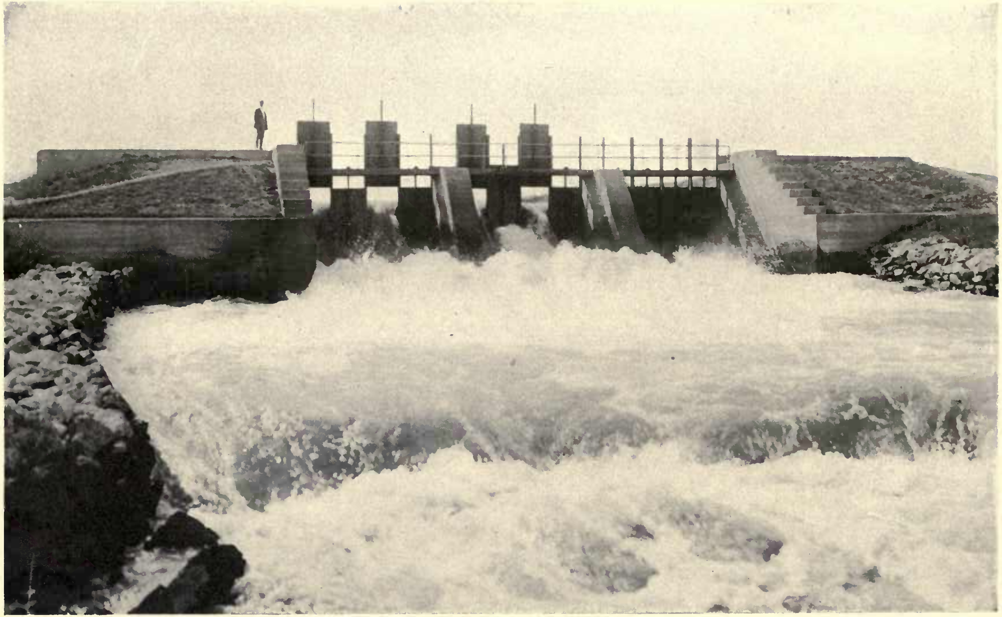


FIG. 34.—Discharge of Boise Main Canal into Deer Flat Reservoir, Boise Valley, Idaho.

few places where hard freezing occurred, which were repaired soon after.

Careful cost records were kept of all the work and the following table covers all expenses of whatsoever nature incident to the work except overhead charges, which would amount to about 4½ per cent.

Item	Unit Cost per Cubic Yard of Concrete	Unit Cost per Linear Foot of Canal
Foundation	\$2.349	\$2.195
Plant	0.858	0.801
Gravel and sand	1.079	1.008
Cement	2.963	2.767
Water	0.222	0.207
Forms	0.177	0.165
Mixing and placing	1.603	1.497
Supplies	0.107	0.100
Superintendence and accounts	0.172	0.161
Engineering	0.098	0.092
Total for concrete	\$7.279	\$6.798
Total for concrete and foundation	9.628	8.993

DEER FLAT RESERVOIR

This reservoir is located southwest of Nampa, Idaho, and consists of an irregular depression in the hills, closed by the construction of embankments in three natural gaps. It has a surface area of 9,800 acres, and a capacity above lowest outlet of 180,000 acre-feet. Following is a table showing capacity at various elevations:

Area and Capacity of Deer Flat Reservoir

Elevation, Feet	Area, Acres	Capacity, Acre-Feet	Elevation, Feet	Area, Acres	Capacity, Acre-Feet
2,485	200	0	2,510	4,500	44,000
2,490	400	2,000	2,515	5,800	69,000
2,495	800	6,000	2,520	7,000	100,000
2,500	1,800	13,000	2,525	8,300	137,000
2,505	3,150	25,000	2,530	9,800	180,000

Upper Deer Flat Embankment.—The upper embankment of Deer Flat has a height of 68 feet and a length of 3,930 feet, and contains 1,170,000 cubic yards of earth and gravel. The water

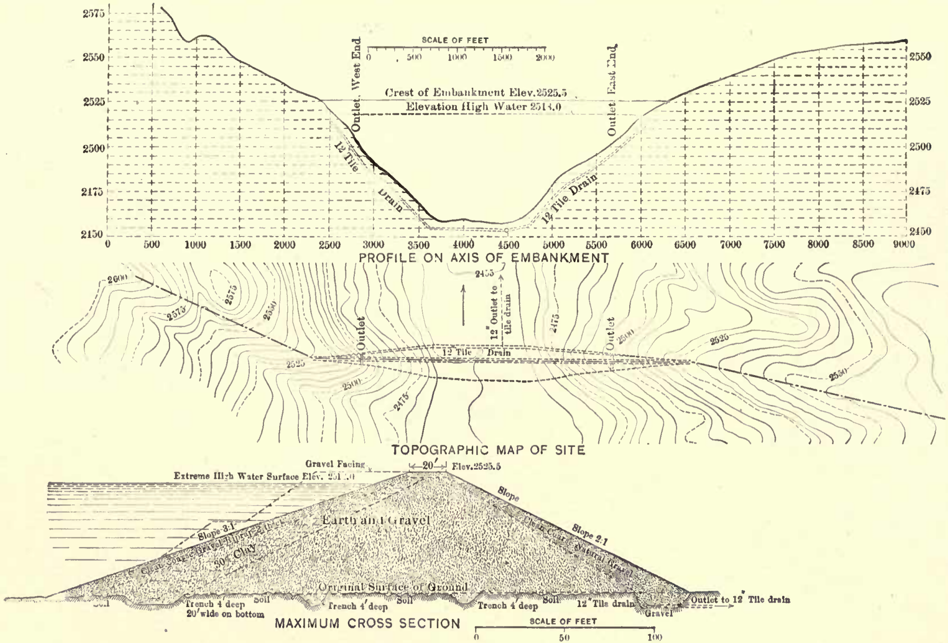


FIG. 35.—Profile, Plan, and Section, Upper Deer Flat Embankment, Boise Valley, Idaho.

slope is 3 to 1, and the lower slope 2 to 1. In addition the water slope is heavily blanketed with coarse gravel.

This structure was advertised and three bids on the earthwork were 36, 37 and 37½ cents per yard, respectively. After careful consideration of the cost, these bids were rejected as being too high, and the work was undertaken directly by the Government.

The following equipment was used to build the dam and outlet at a total cost of $77,000: Two 70-ton Atlantic steam shovels, four locomotives, sixty dump cars, 427,000 pounds of rails, two road machines, five sprinkling wagons, one steam pump, one concrete mixer, two concrete rollers and miscellaneous tools.

The material was excavated with steam shovels and two trains of twelve cars each to attend each shovel.

The material is generally a sandy gravel with small varying proportions of clay. Some selection was exercised to get the material showing considerable proportions of clay in the up-stream half of the dam. A few feet under the natural surface of the ground is a stratum of hardpan usually several feet in thickness, to loosen which some powder was used. Indurated chunks appearing on the bank were broken by the hand use of a sledge hammer.

The railroad track was laid directly on the dam, and after dumping a train-load of material the track was moved about 14 feet by hitching to it a heavy span of horses and dragging it sideways, repeating the operation at suitable intervals. Very little alignment with bars was found necessary. In the meantime, other trains would dump from other parts of the track, and it was easy for two men and one heavy span of horses to attend to the track movement for two trains of cars, until the edge of the dam was reached, when some assistance was necessary to start the track on its way back.

This method distributed the material so evenly over the dam that two road machines were ample to complete the spreading of 300 cubic yards per hour. After spreading, heavy four-horse sprinkling carts were employed to thoroughly wet the material, and also served as effective rollers. Grooved concrete rollers were also employed to complete the packing.

To expedite the work it was decided to pay a premium for large output. In addition to the regular wages, for all yardage over 22,000 cubic yards per shovel per month, reckoning from the fifteenth to the fifteenth of each month, a yardage bonus was

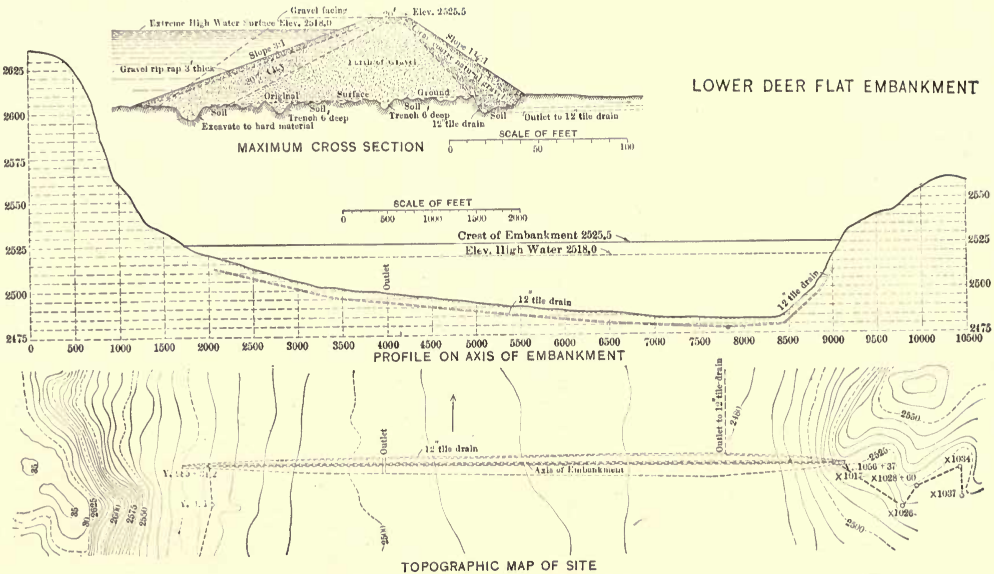


FIG. 36.—Profile, Plan, and Section of Lower Deer Flat Embankment, Boise Valley, Idaho.

paid the steam-shovel and locomotive men and track foremen as follows: Steam-shovel runners, ⅔ cents; steam-shovel cranesmen, ½ cent; steam-shovel firemen, ⅓ cent; locomotive engineers, ½ cent; track foreman, ¼ cent; making a total cost of 3¾ cents per yard.

The costs of this work are shown in table:

TABLE 3—COST OF UPPER DEER FLAT EMBANKMENT

	Per Cubic Yard
Excavation	6.3
Hauling	8.3
Spreading	1.8
Sprinkling	1.8
Rolling	1.3
Depreciation	4.1
Engineering, superintendence and general expense	3.9
Total cost per cubic yard	27.5 cents

Lower Deer Flat Embankment.—The Lower Deer Flat Embankment was built under contract and was completed in January, 1908. It is 7,350 feet long and the greatest height is 43 feet. The body of the dam is of earth obtained from borrow pits within the reservoir. A blanket of gravel 3 feet thick is spread over the water face, and the down-stream fourth of the dam is entirely of gravel.

The earth was loaded into dump wagons by elevating graders, except a small portion which was placed by wheel scrapers. Road machines were used for spreading, and sprinkling carts for sprinkling.

The gravel was obtained from borrow pits near the north end of the dam, the bottom of these pits being nearly level with the top of the dam, so that most of the haul was either down-hill or level. The average haul for gravel was about 4,000 feet, and was made by locomotives and dump cars. The loading was done by a 60-ton Vulcan steam shovel. The principal equipment used on this dam is as follows, the total cost being $50,000: One Vulcan 60-ton steam shovel, two locomotives, thirty-two dump cars, 1½ miles rails and switches, four elevating graders, two road graders, forty-eight dump wagons, two traction engines, sixteen fresno scrapers, five tongue scrapers, nine slip scrapers,

seventeen wheel scrapers, four sprinkling wagons, two concrete rollers, four small gasoline engines, three small centrifugal pumps, fifteen plows, one derrick and miscellaneous tools.

The contract prices were 24 cents per yard for earth and 35 cents per yard for gravel. Allowing a salvage of only 20 per cent on equipment, the total cost to the contractor was 21 cents per yard for earth and 29 cents per yard for gravel, exclusive of administrative expenses, which doubtless left him a satisfactory profit.

Slope Protection.—One of the problems connected with the construction of these embankments was the protection of the water slope against wave action. The extensive area and exposed position of the lake indicated that the wave action would at times be strong and that protection was accordingly important. No rock was to be found in the vicinity of either embankment and the distance from railroad connections made the importation of rock from a distance very expensive. The same conditions made the cost of concrete high and pavement with this material would also be very expensive. The importance of the question was emphasized by the great extent of the water slope in each embankment and it was finally concluded to try the experiment of protecting these slopes by an excess quantity of coarse gravel.

After finishing the dam to the lines required by the drawings, with 3 to 1 water slope and 20 feet top width, the equipment on the ground was employed in widening the top by dumping from cars on the water slope the coarsest material available, moving the tracks outward as the top width of the embankment increased. This material was composed of water-worn sand and gravel, varying from cobbles of 50 pounds weight through all the intermediate sizes to very fine sand, the proportion of coarse material varying somewhat but never great. In this way the upper embankment received about 95,000 cubic yards of extra material, which was deposited on the water slope, taking its natural angle of repose and widening the top of the embankment to 51 to 67 feet. A larger quantity was necessary on the lower embankment, as this is much longer and required about 226,000 cubic yards of material. It is the intention to let the wave action do the rest, keeping close watch for the necessity of any further operations.

As the waves attack the gravel slope, they will gradually

undermine and cause the gravel to creep down the slope. The finest materials will be carried some distance into the lake before being deposited, those a little coarser being washed down the slope with considerable freedom and the coarser materials being moved with less facility. In this way, by an automatic sorting

FIG. 37.—Upper Deer Flat Embankment, showing beaching of gravel slope.

process, the finer materials will be deposited on the bottom of the reservoir near the base of the dam and be of service in making this area more impervious and preventing seepage under the dam. The materials left on the slope will become gradually coarser from the bottom upward and finally the coarsest materials available will be left as a sort of paving or riprap, and in time each material will take the slope at which it can resist the wave action, resulting finally in a flattened slope paved with water-selected, coarse material of gravel and cobbles. Experience with the reservoir has shown that any obtainable tightening of the bottom is very desirable, but it is impossible to tell what influence this sorting process has had upon the large improvement that has been noticed in the seepage conditions since the reservoir was first placed in

service. The reservoir has now been in service five seasons, beginning with 1910, and although the area submerged has increased every year, the seepage during 1914 was less than in previous years, and less than one-third of that occurring in 1911.

During the four past seasons a large amount of water has been stored in the reservoir and extensive wave action upon the embankments has been experienced. During 1913, 1914, 1915, and 1916, the reservoir was practically full in midsummer and the conditions approximate those of normal use of the reservoir.

Profiles of the slopes taken at frequent intervals along both embankments show that several terraces or beaches have been formed at the elevation which the lake happens to hold at the time of wind-storms, but subsequent action tends to obliterate each beach or terrace and to gradually work down the slope and flatten it. At no point, however, has the work of the waves reduced the top width to a dimension approaching that indicated in the original design. See Fig. 37.

At the upper embankment, it will be possible to repeat the processes of gravel reinforcement at least twice before reaching the cost of paving the entire water slope, and it seems certain that this will never be required. At the lower embankment, the advent of the railway since the embankment was constructed opens the possibility of employing either rock or concrete at some future date should further operations appear to be required. The present indications are that considerable economy is likely to be accomplished over the cost of paving the embankment slopes by the usual methods at time of construction.

SEEPAGE LOSSES

A large amount of seepage occurred from the Deer Flat Reservoir when it was first put in service. In 1909, it was filled only a few feet above the gate sills, and but little was used. Of the amount admitted more than three-fourths seeped away, leaving less than one-fourth in the reservoir when refilling was begun in the fall.

In each successive year the reservoir has been filled to a greater height, and a greater area has been submerged, but the percentage of seepage loss has decreased each year. In 1914, the submerged area was greater than any previous year, and the

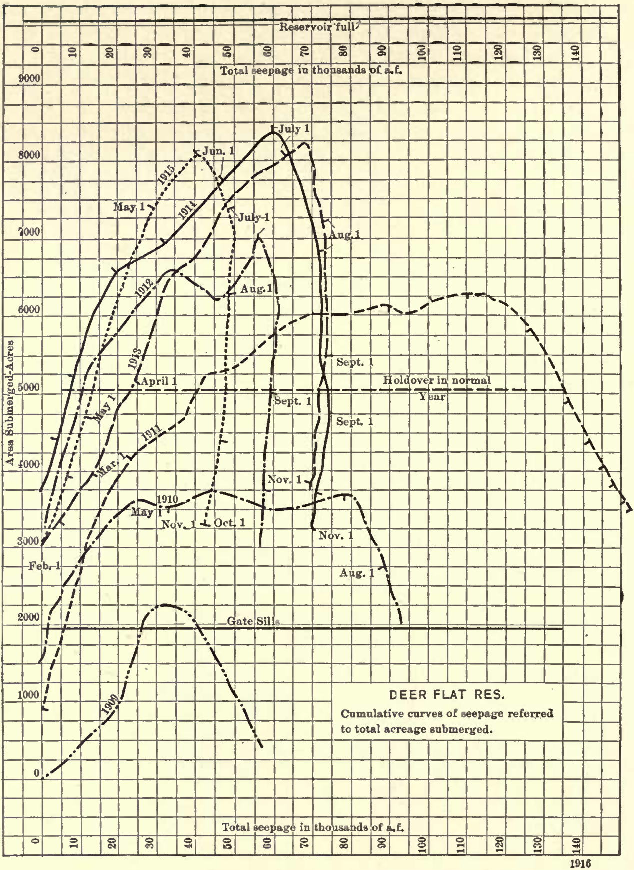


FIG. 38.—Curves of Seepage from Deer Flat Reservoir. Showing the Improvement with Use.

total amount of seepage was actually less than any previous year. The steady improvement is clearly shown in the diagram, Fig. 38.

This shows for the nine months beginning January 1, 1914, a seepage loss of about 9 feet in depth, or 1 foot in depth per month, an average rate of percolation of two-fifths of an inch per day. This is about one-tenth the rate of percolation from canals in good earth and is about what might be expected from a concrete-lined canal. The steady improvement and the remarkable tightness attained are obviously due to the filling of the subsoil with water which can not readily escape and not to any abnormal tightness of the soil.

ARROWROCK RESERVOIR

A thorough reconnaissance of the drainage basin of the Boise River failed to discover any site for storage more favorable than one at Arrowrock, about 4 miles below the junction of the north and south forks of the Boise, and about 22 miles above the city of Boise. At this point, it intercepts the drainage from 2,600 square miles. The storage capacity of this basin is given in the following table:

Area and Capacity of Arrowrock Reservoir

Elevation, Feet	Area, Acres	Capacity, Acre-Feet	Elevation, Feet	Area, Acres	Capacity, Acre-Feet
2,960	8	19	3,100	975	45,083
2,970	31	216	3,110	1,123	55,651
2,980	56	657	3,120	1,252	67,588
2,990	85	1,375	3,130	1,405	80,929
3,000	116	2,391	3,140	1,570	95,878
3,010	147	3,719	3,150	1,741	112,505
3,020	187	5,401	3,160	1,890	130,720
3,030	238	7,538	3,170	2,053	150,517
3,040	304	10,277	3,180	2,228	172,009
3,050	378	13,716	3,190	2,423	195,425
3,060	458	17,934	3,200	2,655	221,004
3,070	540	22,963	3,210	2,864	248,687
3,080	637	28,888	3,220	3,086	278,506
3,090	788	36,105			

Arrowrock Dam.—The canyon at the dam site has high bare granite cliffs on the north side, with a less precipitous slope on the south, the foot of the slope being capped with a wedge of basalt, nearly perpendicular at the river, forming a cliff 70 to 80

feet high, with a level bench intersecting the granite slope further back. This bench and the granite slope above it were covered with a layer of soil and some vegetation. The site of the dam was thoroughly explored by diamond drills, showing a foundation

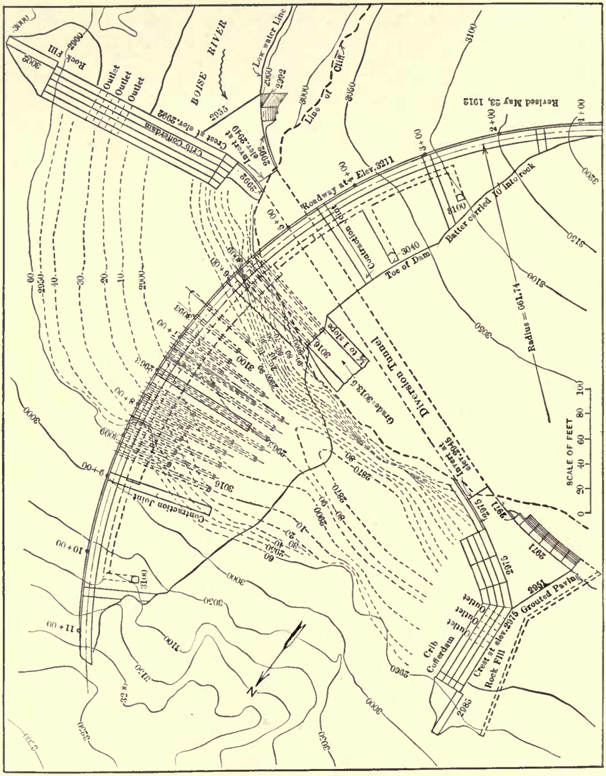


FIG. 39.—Plan of Arrowrock Dam, Boise River, Idaho.

of good granite at a maximum depth of 90 feet below the bed of the river, and a depth of 60 to 70 feet over most of the foundation, the overlying material consisting of sand, gravel, and boulders suitable for use in concrete.

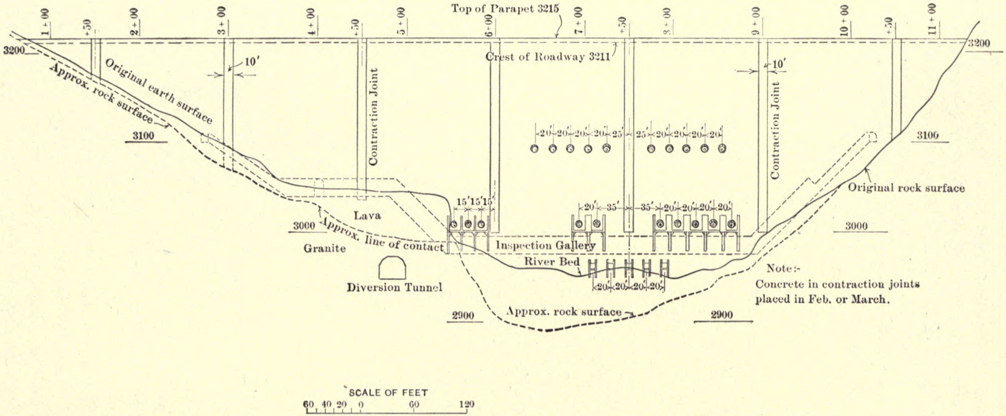


FIG. 40.—Elevation of Arrowrock Dam, Boise River, Idaho.

For the purpose of transporting men and materials for the dam, a railroad was built from Barberton, the nearest railroad point, about five miles above the city of Boise. This road is

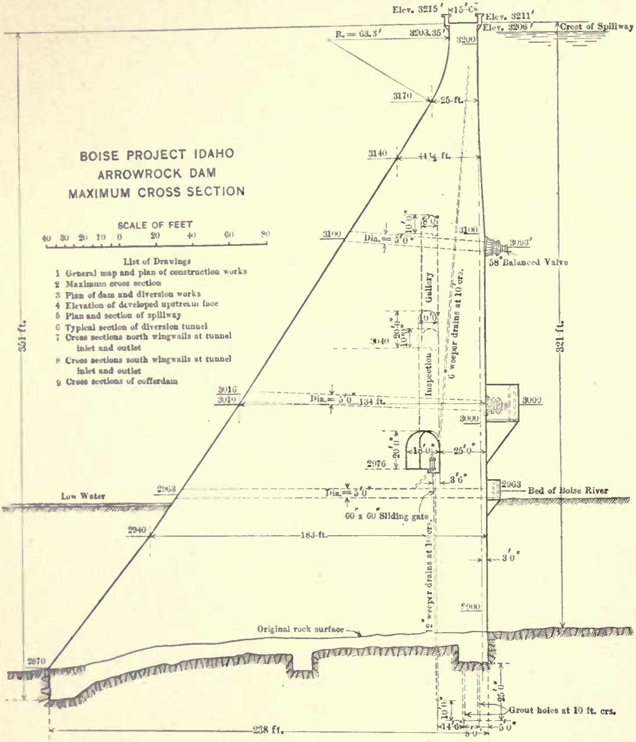


FIG. 41.—Maximum Section of Arrowrock Dam.

standard gage, 17 miles long, with a maximum grade of 1½ per cent and a maximum curvature of 12 degrees. There are two river crossings, one at Gooseneck, consisting of two through trusses of 150 feet each, and the other at Arrowrock, consisting of four deck spans of 68 feet each.

The dam is built of concrete with about 20 per cent of stones, or "plumrock" imbedded therein. The plan of the dam is on a radius of 670 feet, measured to the parapet wall. No dependence, however, is placed upon arch action, the profile being computed as a gravity structure, with pressures limited to 30 tons per square foot, reservoir full. The maximum height of the dam is 354 feet from lowest foundation to top of parapet. The dam is about 200 feet long at river-bed and about 1,060 feet at the roadway over the top.

In order to prevent leakage in the foundation of the dam, a line of holes was drilled into the foundation just below the up-stream face of the dam to depths of 30 to 40 feet. They were grouted under pressure, but the solidity of the rock was such that it took but little grout. About 20 feet down-stream from the grouted drill holes, another line of holes was drilled to serve as drainage holes to relieve any leakage under the dam. These were continued upward into the masonry and emerged into a large tunnel running the entire length of the dam described below.

At intervals of 100 feet, radial contraction joints are provided where adhesion is prevented by forming and oiling, but which are closed as tightly as possible.

A drainage tunnel is provided about 25 feet inside the water face of the dam, following just above and parallel to the natural ground surface into which the wells in the foundation emerge and into which they will discharge any water they may receive under pressure. In the river channel portion of the dam this tunnel is made 25 feet wide and 30 feet high, giving room for the operation of drilling machinery in case a need for further grouting in the foundation should develop. The tunnel has an entrance at each end, and an additional one near the left end.

A radial branch tunnel leads to the down-stream toe of the dam to discharge any drainage water that may appear. Drainage wells extend upward from the main tunnel nearly to the top of the dam, at intervals of 10 feet, to intercept and discharge water percolating into the masonry.

Spillway.—A spillway is provided at the right bank consisting of a concrete lip 250 feet long, 10 feet below the top of the parapet of the dam. Over this lip the surplus water will flow into a concrete channel growing wider and deeper down-stream. The spillway will be provided by a movable crest operating automatically

to open as the water approaches the top of the dam, and closing as it recedes. The open spillway has a rated capacity of 40,000 cubic feet per second which is much greater than the volume of any recorded flood. It will discharge its waters into the canyon of Deer Creek, which flows into the river some distance below the dam.

Control Works.—The lowest outlet from the Arrowrock Reservoir is at elevation 2,955, about the original bed of the river. It consists of five radial conduits through the dam, each controlled by duplicate slide sluice-gates, designed to operate under about 60 feet head when the water is too low in the reservoir to be drawn in sufficient quantity from the conduits above. The gates are 5 feet square, discharging into a special cast-iron conduit 5 feet square of entrance, and warping to a circle of 5 feet diameter in its length of 8 feet, the conduit below this being composed of rich concrete, circular in form and five feet in diameter. Each gate is controlled by a piston and stem working in a cylinder in a chamber above operated by oil pressure tested to 600 pounds per square inch. The cylinders are of cast steel, 24 inches internal diameter, with wales ¾ inch thick. The position of these gates is shown on drawing, Fig. 40.

Another set of radial conduits, seven in number, are placed with their centers at 3,009 at the reservoir end, and 4 feet higher at the down-stream end, to insure their filling with water when in use. In each of these conduits is placed a balanced valve operating by water pressure of the Ensign type. The diameter of each valve is 58 inches. Three other similar conduits, similarly controlled, are provided at the same level, on the left bank, just above the natural ground level destined for use in developing power at some future time.

At elevation 3,093, 113 feet below the spillway, ten conduits similar in all respects to those above mentioned are provided, making twenty-five outlets in all. The balanced valves above mentioned are 58 inches in diameter and discharge through 52-inch conduits. Each consists of a semi-steel cylinder closed at the outer end, in which slides a piston, the inner end of which forms a needle operating to regulate the amount of water discharged and closing similar to a check valve. This piston may be removed by removing the cylinder head. It is kept in alignment with the axis of the cylinder by bronze guides.

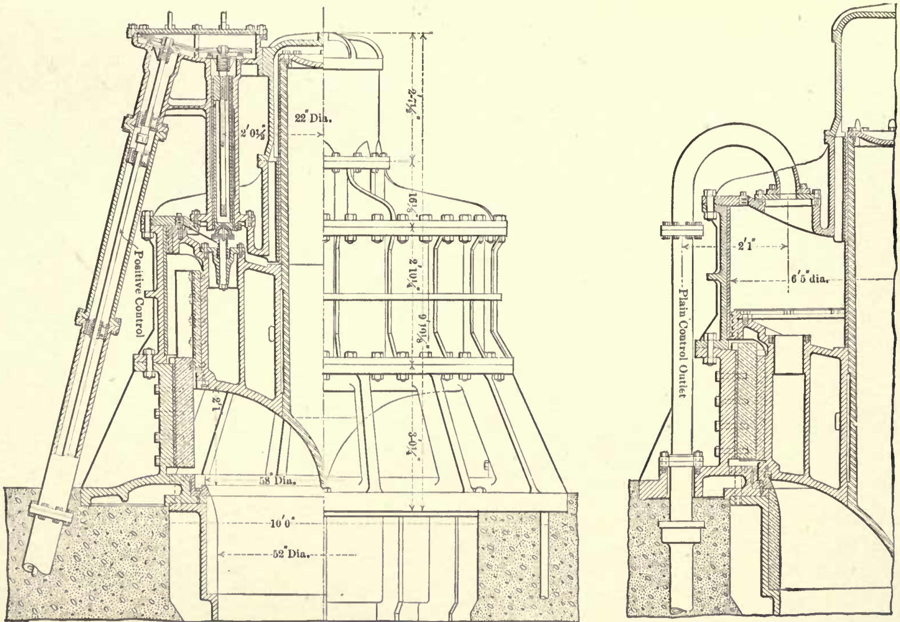


FIG. 42.—Section of Balanced Valve, Arrowrock Dam, Boise River, Idaho.

It is opened and closed by the regulation of the pressure of water behind the main piston, the pressure being supplied by the restricted leak past the piston, and relieved by a drain or control pipe leading out from the cylinder head. To open the valve the pressure on the piston is reduced by opening the outlet of the control pipe. As long as this discharges freely the valve will continue to move until completely open, and it may be stopped at any point partially open by properly regulating the leakage through the control pipe. To close the valve, the outlet from the control pipe is closed and pressure applied from a tank far above the reservoir to start the piston, after which it will slowly close itself, the rate of movement depending on the volume of leakage around the piston.

In order to give positive and accurate regulation of discharge from the reservoir a positive control is also provided as shown in the drawing. The leakage is regulated by a movable sleeve fitting over a conical seat which stops the leakage when closed, and when opened permits the escape of water thus removing the pressure from that side of the piston, causing the valve to open. The valve thus follows the sleeve, maintaining just enough area between the sleeve and the conical seat to regulate the leakage to the quantity required for balance. The sleeve being movable at will, by means of a hand-wheel, rod, and screw, the position of the valve can be accurately controlled. An indicator is provided to show the position of the valve at any time.

CONSTRUCTION OF THE ARROWROCK DAM

This entire work was done by Government forces, under specifications as carefully drawn as for contract work.

For construction purposes, the river was diverted by a crib cofferdam into a tunnel driven 487 feet through the rock point forming the left abutment. This tunnel is 30 feet wide and 25 feet high, its arched top having a rise of 10 feet. The bottom and sides were lined with concrete and the top with timber. The entrance and exit were both made bell-shaped to avoid loss of head and give the tunnel the greatest possible discharge.

For the sake of economy, the excavation first made was of a width, up- and down-stream, only sufficient to permit the construction of one-half the base of the dam, and the up-stream portion of the dam was constructed on a gravity section to a height about

Fig. 43.—Arrowrock Dam and Spillway, looking upstream, Boise River, Idaho.

40 feet above the low-water datum. This work was accomplished between flood seasons, which would not have been possible had the entire excavation been completed before concreting began. By this means, also, it was possible to install a screening and mixing plant in the pit close to the work and use the unexcavated sand and gravel so that this was put directly into the work without being taken out of the pit. The completed section of the dam then served as a most effective cofferdam to prevent flood damage to the work, and to prevent seepage from the up-stream side into the pit during the remainder of the excavation and construction.

Equipment.—Two Lidgerwood cables of 1,500 feet span, with a capacity of 15 tons each, were anchored into the granite mountain sides and supported on towers in such a position as to command the entire length of the dam. These were operated by electric engines, and were employed in excavating and transporting equipment and materials for construction. Four ten-ton derricks were installed, as well as several smaller ones. A dragline excavator with a 2½-yard bucket was used also in excavating the foundation, from which 225,000 cubic yards of material were removed. Four ten-ton derricks were installed as well as several smaller ones. A seventy-ton steam-shovel was used in the upper part of the excavation, especially at the right abutment, and was afterwards employed in excavating the spillway.

A screening and crushing plant and three one-yard mixers were installed on the bench at the left abutment.

The concrete used in the dam was composed of about 1 part sand-cement, 2½ parts sand, 5½ parts gravel and 3 parts cobbles passing a 5½-inch grizzly, with a somewhat richer mixture at the water face of the dam. So far as available the sand, gravel and cobbles were obtained from the river-bed excavation. This was sufficient for about one-fourth of the dam; and the rest was hauled 14 miles by rail from a pit above the Boise Diversion Dam, where a screening and crushing plant was installed.

The concrete was placed in the dam mainly by the pouring system.

On the left bank, on top of the lava bench, was installed the concrete mixing plant, consisting of three independent units, each consisting of a one-yard mixer served from appropriate measuring boxes and bins, and discharging into a two-yard hopper, the gate of which was operated by hand. From each mixer ran a two-yard trolley dump car which carried the concrete to a distributing tower

where it was dumped into one of three two-yard cableway buckets. These buckets dumped automatically through radial gates into a cableway hopper from which was suspended a chute, the lower end of which was supported from auxiliary cables, and which may be swung around a complete circle, commanding all points within a radius of 40 feet. The position on the main cable of the cableway hopper was controlled from the head tower, and by simply moving this along the cable the location of the work was changed at will.

The cement used in the dam was composed of standard Portland cement, reground at Arrowrock with a little less than an equal amount of granite sand to a fineness such that 90 per cent would pass a No. 200 standard sieve.

The mill for this purpose consisted of a rock crusher, a pair of sand rolls, a ball mill and four tube mills, and had a capacity of 2,000 barrels in twenty-four hours. After grinding the sand-cement was carried across the river in a 4-inch pipe by compressed air. Besides the rigid fineness test above noted, the sand-cement was required to pass all the standard physical tests for Portland cement, and not a single case occurred where the sand-cement failed to meet the standard requirements for strength or failed on the boiling test. Concrete made of sand-cement was slower in setting and in hardening than that made from the straight Portland cement of the same brand as that used in making the sand-cement.

The cost of the mill for grinding the sand-cement was $50,000, distributed about as follows:

Excavation	$ 1,500
Foundations	4,000
Erection of building, chutes, etc	8,500
Equipment, including freight	25,000
Installation of equipment	9,000
Electrical work	2,000
	$50,000

The cost of manufacturing sand-cement of 45 per cent sand by weight averaged about as follows:

Granite delivered to crusher	$0.01
Portland cement, including freight	1.35
Handling and storing Portland cement	.08
Labor operating mill	.10
Current for power and lighting	.16
Supplies, depreciation and repairs	.15
	$1.85

Boise Storage Unit—Arrowrock Dam
March 31, 1916

Item	Unit	Quantity	Cost to the United States		
			Unit	Total	Feature
1. Preliminary Examinations and Surveys: (Tests and surveys Twin Springs, Alex. flats and North Fork Reservoir)	....	......	....	....	$ 8,594.86
2. Arrowrock Reservoir: preliminary:					
Wash borings	Lin. Ft.	3,008	$ 6.66	$ 20,057.06	
Core drillings	"	2,670	9.18	24,488.25	
Test pits, tunnels, etc	....0....	....	....	11,035.61	
Clearing and grubbing	....	....	....	4,732.40	
Right of way	....	....	....	70,423.76	
Water rights	....	....	....	20,000.00	
Plant and administrative, etc	....	....	....	116,132.28	266,869.36
3. Arrowrock Dam Proper:					
Excavation, Classes 1 and 2	Cu. Yd.	200,090 }	2.019	651,382.27	
Excavation, Class 3	"	122,300 }			
Concrete (body of dam)	"	585,165	5.033	2,945,341.35	
Backfilling	....	....	....	518.56	
Grouting	Lin. Ft.	10,490	2.09	21,930.78	
Machinery and installation: (Includes twenty 58-inch balanced valves at 47,500 lbs. each and five sluice-gates.)	Lbs.	2,672,301	.09	235,981.25	3,855,154.21
4. Log conveyor: Excavation	Cu. Yd.	8,265	.84	6,941.25	
Concrete	"	2,134	12.67	27,035.16	
Miscellaneous	....	....	....	183.49	
Machinery and installation	Lbs.	254,190	.079	19,970.05	54,129.95

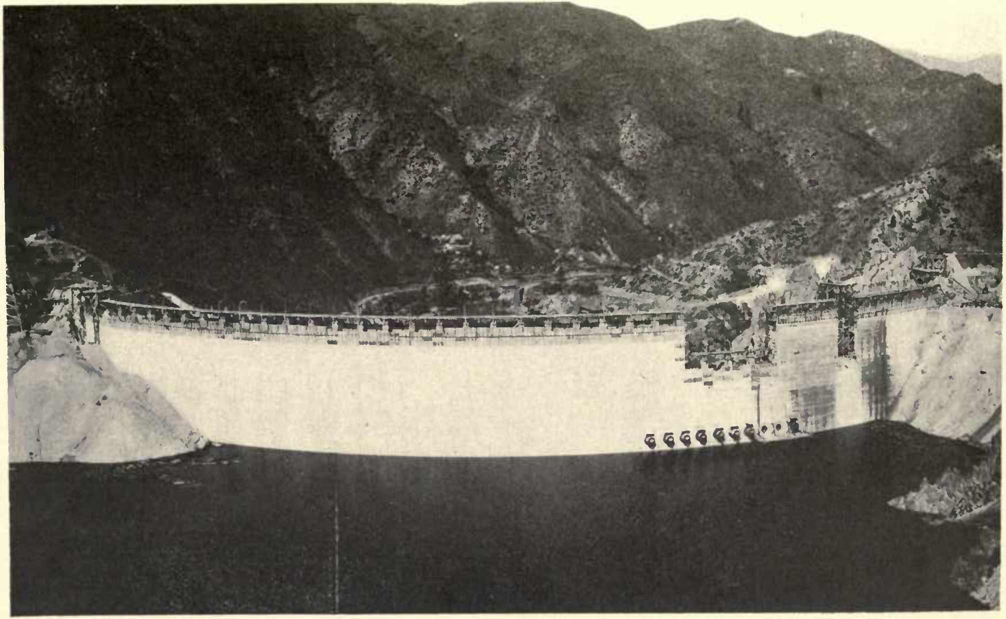


FIG. 44.—Arrowrock Dam, looking downstream, Boise River, Idaho.

BOISE STORAGE UNIT—ARROWROCK DAM
MARCH 31, 1916
Continued

Item	Unit	Quantity	Cost to the United States		
			Unit	Total	Feature
5. Gantry crane for dam					523.49
6. Power, preparatory at dam					19,410.81
7. Spillway: Excavation,					
Classes 1 and 2	Cu. Yd.	17,250	.863	$ 310,320.81	
Class 3	"	341,850			
Concrete	"	25,424	8.52	216,733.09	
Miscellaneous				223.26	
Machinery and installation	Lbs.	642,370	.077	49,618.60	
Riprapping	Sq. Yd.	60	7.63	457.94	577,353.70
8. Bridge, 96 feet, steel	Lbs.	50,200	.075		3,741.23
9. Administrative as whole					3,610.39
10. Power system diversion dam					195,305.27
11. Lands and improvements:					
Buildings				4,229.18	
Roads	Mi.	22.8	3,275.00	74,701.37	
Miscellaneous				108.02	79,038.57
12. Telephone System	Mi.	46.1	209.87		9,675.20
Grand total, March 31, 1916					$5,073,407.04

Power-Plant.—With the exception of the steam shovel, all the machinery about the plant was run by electric power. To furnish this a plant was installed at the diversion dam previously described, between the fishway and the head-gates of the main canal. The power-plant consists of three units, each of which is composed of an 850-horse-power turbine water-wheel directly connected to a 625-KVA generator. The available fall is about 30 feet. The current generated is three-phase, 60-cycle, alternating current at 2,300 volts direct-connected to three-phase transformers, which step the current up to 22,000 volts, at which it is transmitted to Arrowrock by duplicate lines of wires, where it is stepped down to 440 volts for use on the work. The motor installation is about 3,000 horse-power. The two cableways each require 300 horse-power, the sand-cement plant 500, and air compressor 125; 1,180 horse-power was provided for pumping four 75-horse-power derrick motors, and a number of smaller motors for mixers, rock crushers, shop machinery, and other uses.

The canals of the Boise Project serve lands lying above those previously irrigated. Most of them are rolling bench lands, and although some bottom-lands on the right bank of Snake River are also included, these are generally sandy and rough. The system for distributing irrigation water is, therefore complicated and expensive, requiring tortuous canals, and a large number of drops, chutes, pressure pipes, etc. These are generally of concrete for the sake of safety and permanency, though a few problems were successfully solved by means of steel and wood. In lowering the water from the bench to the Snake River bottom several drops of great elevation were needed; the smaller were in the form of pipes, and the larger were open chutes with the following elements:

CONCRETE CHUTES ON BOISE PROJECT

No.	Length Feet	Drop Feet	Second-Feet	Volume Cu. Yd.	Cost	Unit Cost
1....................	430	73	130	276	$4,610	$16.70
2....................	325	42	120	121	2,190	18.10
3....................	358	50	100	217	3,624	16.75
4....................	993	79	36	283	4,528	16.00
5....................	150	27	36	75	1,575	21.00

The chutes are located at points where the necessary fall can be compressed into the shortest practicable distance. They are

all similar in design and consist essentially of an inlet structure, a trough to conduct the water down the hill, and a pool at the bottom to receive the water and destroy its accumulated energy. The inlet structure forming the transition is provided with splayed wing walls, and well equipped with numerous and deep cut-off walls for the wing walls, floor, and sides to prevent percolation of water along the structure. At the lower end, where the water enters the trough, it is provided with control gates. The trough converges to a narrow channel a short distance below the gates, to correspond to the increased velocity, which usually reaches about 40 feet per second, the section again increasing as it approaches the pool at the bottom. Cut-off walls are provided under the trough at frequent intervals to prevent erosion by leakage or rain-water. These are generally one foot deep, except at expansion joints, where they are deeper. The floor is 9 inches thick and the sides have thicknesses of 8 inches at top and from 9 to 10 at the bottom, being 2 feet in height.

The rolling, irregular character of much of the country to be served with water required a very complicated distribution system, and numerous crossings of drainage and other depressions were necessary. Where the depression to be crossed was deep, and where excess grade was available, pressure pipes were used, usually of concrete, but in a few instances of wood.

Where the depression was not too low and saving of grade was desirable, steel flumes were installed on wooden trestles with concrete footings. Some of the longer and more important of these are listed in the table on page 130.

Wages of foremen were from $3.50 to $4.00 per day; carpenters, $3.20 to $3.50; laborers, $2.50; teams, $2.50.

The flumes listed were all of galvanized iron carried on wooden trestles built of red fir from the Pacific Coast and founded on concrete pedestals from 2 to 3 feet high.

The Forest pressure pipe receives water from a canal on the Boise Project and conducts it a distance of 8,575 feet across the valley just below the lower Deer Flat embankment, to irrigate 2,800 acres of land near Caldwell. It has an internal diameter of 36 inches, and a shell thickness of 3 inches. Its fall is 45 feet, and its capacity about 50 second-feet. The maximum head under which it operates is about 70 feet, and two-thirds of the line carries a head exceeding 60 feet.

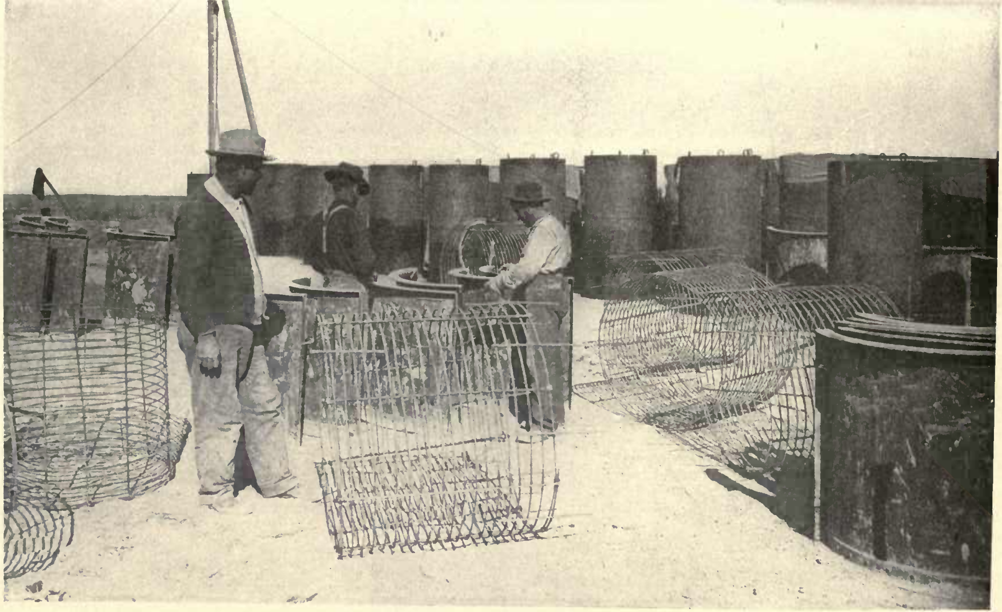


Fig. 45.—Steel Forms and Reinforcement for Concrete Pressure Pipe, Boise Project.

STEEL FLUMES—CALDWELL DIVISION, BOISE, IDAHO

Name	Size Inches	Length Feet	Highest Bent Feet	Capacity Sec.-Feet	Haul Miles Lumber Cement	Total Cost	Unit	Year
Deer Flat N....	108	1,600	10	40	7½	$5,417	$3.38	1909
Knor..........	60	70	8	3	9½	201	2.87	1910
Nordica No. 1..	84	874	17.8	18	8½	7,995	3.43	1910
" No. 2..	60	864	7.5	6	9	1,949	2.26	1911
Stansell..	48	841	17	4	9½	2,173	2.58	1911
Aldrich........	36	1,270	22.8	3	15	2,210	1.75	1911
Lizard No. 1...	84	134	6.5	26	10	659	4.92	1911
" No. 2...	60	112	7	10	10½	529	4.72	1911
Lemaster......	48	300	7	5	16½	876	2.92	1911
McIntire.......	60	2,000	14	10	14	5,245	2.62	1911
Deer Flat low 1.	132	112	5	106	14	1,245	11.12	1911
" " " 2.	72	234	16.5	19	21	1,195	5.11	1911
" " " 3.	60	1,950	9	7	23	4,128	2.12	1911
" " " 4.	48	520	6.5	4	25	1,142	2.20	1911
Yarnell.... ..	72	4,892	27.8	17	15	12,810	2.62	1911
Mora..........	108	2,963	13.8	43	11	11,320	3.82	1911
Forest.........	96	1,000	18.8	24	11	2,558	2.55	1911
Rogers........	48	50	7.5	3	13	263	5.26	1911
Plowhead......	60	375	9	7	4½	1,099	2.93	1912
Van Tress No. 1	84	3,340	21.5	32	1½	7,549	2.26	1912
" " No. 2	60	850	9	9	3	2,021	2.27	1912
Farley.........	48	890	22	4	2½	1,781	2.09	1912
Arena.........	132	120	16	65	5	827	6.89	1912
Chance........	84	3,230	21	32	7	4,105	1.27	1912
NAMPA DIVISION								
Robinson......	60	320	22	14	3	999	3.12	1909
Bray..........	84	80	8	19	2	483	6.04	1909
Ridenbaugh....	144	200	42	88	1	4,206	21.03	1910
McCleneghan...	48	1,304	7	6	4	2,608	2.00	1910
Barth.........	108	213	7	30	5	1,166	5.47	1910
Riden, H. L....	108	275	12	27	8	1,477	5.37	1910
Bernard.......	192	428	25	215	11	6,423	14.98	1911
Pickle.........	192	240	16	179	11	3,185	13.28	1911
Waldvogel No. 3	84	1,190	25	20	7	3,326	2.78	1912

At each end the pipe is provided with a reinforced-concrete weir-pool and weir. Manholes are provided at intervals of about 1,200 feet, each consisting of a cast-iron saddle, with 10 by 15 inches opening, with cover bolted on. Two throttle valves are provided for the purpose of controlling the flow of water so as to make it act under full head at any stage of discharge. There are also two blow-off valves at the bottom of the valley.

The pipe is built in sections 6 feet in length, reinforced with

$^5/_{16}$ steel wire and joined by concrete collars, 3 inches thick and $8\frac{1}{2}$ inches wide, reinforced in two directions.

The sections of pipe were manufactured in a yard centrally located, where facilities for first-class work were provided, and,

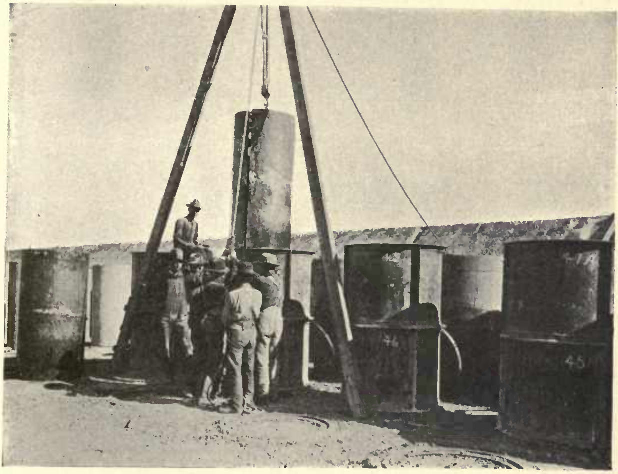


FIG. 46.—Removing Inside Steel Forms from Concrete Pressure Pipe, Boise Project.

after curing, were on the advent of cool weather hauled on wagons and placed in the trench with portable A-frame derricks.

The trench was carefully excavated to grade, and heavy plank was made to give solid and uniform bearing for the tile. A crew could lay and join with collars from 60 to 70 of these tiles per day. Before placing the tiles the ends were brushed with a wire broom to remove all loose particles. They were carefully fitted, and the joint calked from the inside with a mortar of cement, sand and hydrated lime in the ratio of 3:6:1. As soon as this had set the forms were placed for the collars, and these were poured of wet concrete, carefully worked to place with curved rods. The collars were of one part cement to three parts sand and gravel passing $\frac{5}{8}$-inch mesh. The calking and collars were kept moist

for several days, and finally the inside was coated with a cement wash. As soon as the setting was complete the trench was backfilled to a depth of about 1 foot over the pipe, and the pipe was tested with water. A number of minute leaks appeared, but soon disappeared by running the water slowly through the pipe laden with sawdust, no repairs being required.

The following table of costs includes all overhead and other charges of every nature:

	Cost per Foot
Tiles, concrete and labor	$1.13
Reinforcement	.85
Collars	.38
Placing in trench	1.16
Structures at ends	.31
Plant depreciation	.32
General expense	.35
Total cost per foot of pipe	$4.50

DRAINAGE WORK

Prior to the passage of the Reclamation Act, two large irrigation districts were organized in the Boise Valley, called the Pioneer and the Nampa-Meridian districts. These districts had provided some water for irrigation, but a large part of their lands either had no water at all, or a supply of flood water that failed in July, leaving the lands dry in the late summer and fall.

Excessive application of flood waters and seepage from canals gradually filled the subsoil and caused the rise of the ground water plane in the lower parts of the districts, so that the advent of the Government into the valley found these lands in need of both irrigation water and drainage.

Accordingly a contract was executed with the Pioneer district, by the terms of which the Government agreed to expend a sum not exceeding $350,000 in the construction of large drainage ditches, and the district on its part agreed to repay this amount under the terms of the Reclamation Laws, and also engaged to assess and collect water-right charges from all the lands within the district needing additional water supply. The drainage work described in this contract was performed within the specified cost, and a large balance was devoted to additional drainage work described

in supplementary contracts. The work was performed with two electric drag-line scrapers, the current being obtained from the local hydro-electric company. The high-tension transmission lines were tapped by branches built to the vicinity of the work,

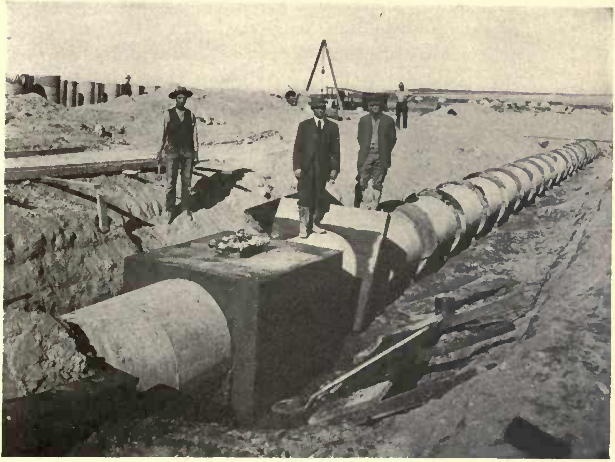


Fig. 47.—Manhole and Concrete Collars on Concrete Pressure Pipe, Boise Project.

and flexible connection made by means of insulated armored cables leading to a small transformer on runners, which was moved with the excavator. The payment for current was 1½ cents per kilowatt-hour.

Cost of Drainage to May 31, 1915, Pioneer District

Investigations and surveys	$ 9,244
Right of way	5,081
General expense	18,200
Installation and operation of repair shop	7,408
Plant and equipment	30,689
Installation and moving equipment	3,510
Electric power	21,803
Crossings and other structures	51,264
Operation of excavating machines	73,483
	$220,682

	Quantity	Cost
Amount excavated in cubic yards............	1,755,238 at	$0.08 per cu. yd.
Length of drains in linear feet...............	264,772 at	.52 per lin. ft.

A contract has been made with the Nampa-Meridian District similar to the one with the Pioneer District.

In the southwestern part of the Boise Valley, the open sandy soil has led to excessive application of irrigation water and has also caused much seepage from the distribution canals and laterals. The seepage waters collect on the lower levels, and have caused the rise of ground water and some water logging of parts of the Fargo Basin.

Drainage work has accordingly been inaugurated in the region affected, and about $40,000 has been expended upon it.

Summary of Feature Costs, Boise Project

Preliminary surveys, borings, etc................	$ 62,520
Arrowrock Dam and outlet works...............	5,073,407
Power-plant at Boise Diversion Dam...........	240,000
Railroad, Barberton to Arrowrock..............	394,000
Diversion Dam in Boise River.................	362,182
Main Canal Boise Dam to Deer Flat Reservoir..	1,650,887
Distributing system from Main Canal..........	1,289,656
Deer Flat Reservoir..........................	966,200
Distribution system from Deer Flat Reservoir....	983,207
Drainage..................................	300,000
Office Building in Boise......................	21,749
Penitentiary Canal..........................	22,849
Farm unit surveys, water studies, etc............	67,306
Telephone system...........................	34,378
Operation and maintenance....................	525,231
Total.................................	$11,993,572

The Deer Flat Embankments and Boise Diversion Dam were constructed by Mr. F. C. Horn, under the general direction of D. W. Ross, as Supervising Engineer. F. W. Hanna later designed and built the distribution system with its numerous structures, and Chas. H. Paul built the Arrowrock Dam under the general direction of F. E. Weymouth as Supervising Engineer. A. J. Wiley has been Consulting Engineer from the first.

CHAPTER VIII

MINIDOKA PROJECT

GENERAL OUTLINE

The waters of Snake River are diverted about 6 miles south of the town of Minidoka by means of a dam which serves also for storage and power development. About 70,000 acres are irrigated by gravity, mainly on the north side of the river, and a few small tracts interspersed among the gravity lands are served by small pumping plants raising water from the gravity canals. The south side canal irrigates about 1,200 acres by gravity, and supplies three large pumping plants which raise water to 48,000 acres of land, an average lift of 64 feet.

The water supply is derived from Snake River, the low water flow of which was previously appropriated. Storage is provided in Jackson Lake, Wyoming, on the south fork of Snake River, where the winter waters and the surplus flood flow of May and June are held for use in late summer and autumn.

More than 200,000 acres of land are irrigated from Snake River, a short distance below the project, and it is necessary that the water used there shall pass the Minidoka Dam. All this water is therefore available for the development of power under the head available at the dam, an average of over 40 feet. About 10,000 horse-power has been there developed, most of which is used for irrigation pumping, but the towns of Rupert, Heyburn and Burley are provided with current for light, heat and power.

MINIDOKA DAM

The Minidoka Dam is a combination of rockfill backed with earth on the water side built in the canyon of the river, and continued on the basalt mesa to the south, in the form of a concrete weir, which serves as a spillway. The weir is provided with a movable crest, consisting of a series of buttresses against which are placed flash-boards to store flood waters for irrigation. Before

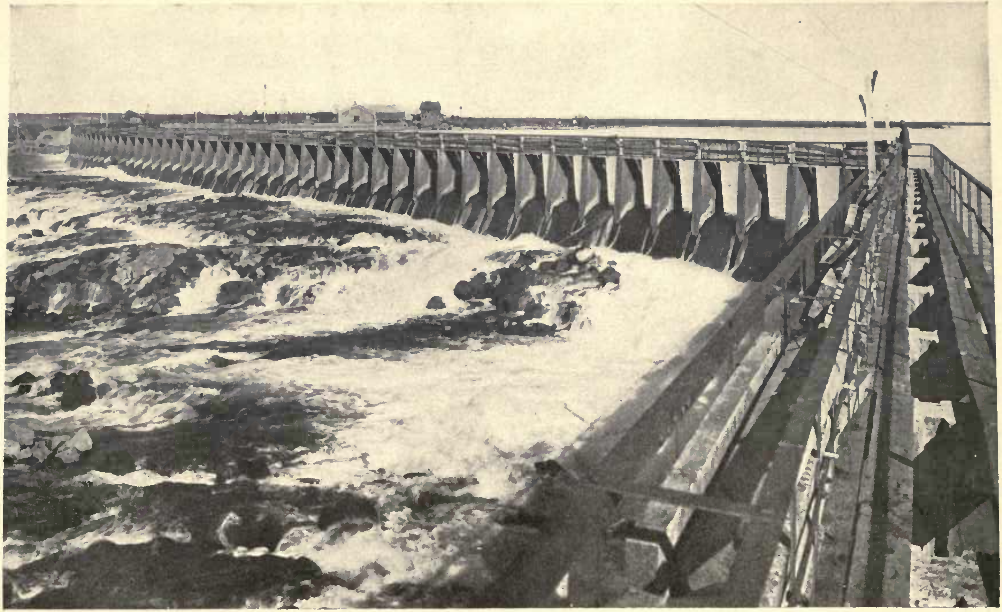


FIG. 48.—Spillway of Minidoka Dam, Power-House in Distance, Idaho.

the height of the flood season in early June the flash-boards are removed to allow the floods to pass over the weir, and as the flow subsides they are replaced in order to hold and store as much of the surplus water as may be. The available storage capacity above level necessary for diversion purposes is about 54,000 acre-feet, and the area of the lake at full capacity is 11,350 acres.

The dam and head-works connected therewith were built by contract in 1906 and 1907. The contract included a portion of the North Canal in rock section.

For handling the rock, two aerial cableways were provided, each having a span of 1,150 feet with capacity of seven tons. The towers were 81 feet high, and were mounted on trucks which moved on tracks normal to the axis of the dam. These cableways handled steel skips with capacity of 3 cubic yards. The rock not within reach of them, it was hauled to them on tramways for distances up to 900 feet. The rock was required to be dropped from 20 to 60 feet into the dam in order to consolidate it, so that it forms a very compact mass.

A channel was cut through the basalt rock on the north side of the river, through which to divert the river during construction, and was provided with a bulkhead of concrete containing six rectangular openings, 8×12 feet, equipped with cast-iron gates. Through these openings the low water flow of the river passed during construction, and by closing the gates after the completion of the dam the water was raised into the canals 38 feet above the river-bed and the surplus forced over the spillway. The rock taken from the diversion channel was deposited in the dam by means of the cableways, to form first a cofferdam and finally to become the rockfill portion of the permanent dam.

The earthfill was composed chiefly of sand and gravel, with selected material containing clay for the water slope, which was protected by riprap of basalt rock.

The earth was obtained mainly on the south side of the river within 1,500 feet of the dam, and was hauled in tram-cars by horses, and dumped from the rockfill into water, the rock being first partially closed with small rock and gravel.

A concrete corewall was built on bed-rock entirely across the river, and brought from 5 to 13 feet up into the fill at the up-stream toe of the rockfill, forming a water-tight junction between the earth and bed-rock.

COST OF MINIDOKA DAM AND HEAD-WORKS

Kind of Work	Unit	Quantity	Contractor's Cost Total	Contractor's Cost Unit	Contractor's Earnings Total	Contractor's Earnings Unit	United States Cost Total	United States Cost Unit	Actual Cost Total	Actual Cost Unit
Div. chan. Class 1 Earth..	C. Y.	20,492	$4,723.51	.23	$3,073.74	.15	$3,411.71	.17	$5,061.48	.25
" " " 3.......	"	5,284	3,700.01	.70	3,434.47	.65	3,733.44	.71	3,998.98	.75
" " " 4 rock...	"	51,913	59,449.78	1.14	46,721.70	.90	49,358.00	.95	62,086.08	1.19
Canal and spill., Class 1..	"	15,686	3,676.39	.23	2,352.84	.15	3,722.58	.24	5,046.13	.32
" " " " 3..	"	2,537	707.63	.28	1,649.17	.65	1,676.97	.66	735.43	.29
" " " " 4..	"	46,333	60,290.66	1.30	32,433.10	.70	33,721.96	.72	61,579.52	1.33
" " " overhaul...	"	9,024	304.61	.03	135.36	.01	135.36	.01	304.61	.03
" riprap............	S. Y.	4,078	2,026.58	.50	5,097.00	1.25	5,097.00	1.25	2,026.58	.50
Dam-placing rock.........	C. Y.	75,025	58,042.58	.79	67,522.50	.90	70,865.42	.94	61,385.50	.83
" " earth.......	"	139,955	61,172.15	.44	111,964.14	.80	115,427.65	.82	64,635.66	.46
" riprap............	S. Y.	5,864	3,798.66	.65	11,727.78	2.00	11,855.25	2.02	3,926.13	.67
" concrete...........	C. Y.	2,700	14,166.22	5.24	16,197.36	6.00	23,330.78	8.63	21,299.64	7.88
" excavation (wet)....	"	860	5,236.80	6.16	2,550.90	3.00	2,686.92	3.16	5,372.82	6.32
Spillway, concrete.......	"	4,180	16,426.01	3.93	20,899.50	5.00	33,228.91	7.95	28,755.42	6.88
Embankment, rock......	"	4,296	1,942.59	.45	3,222.00	.75	3,536.45	.82	2,257.04	.53
" earth......	"	6,722	1,944.53	.29	3,361.00	.50	4,013.85	.60	2,597.38	.39
Canal, concrete..........	"	1,109	5,362.97	4.83	7,765.80	7.00	10,958.82	9.88	8,555.99	7.72
" steel.............	Lbs.	15,048	860.00	.06	1,203.84	.08	1,320.00	.09	976.16	.06
" cast-iron gates....	"	35,041	4,507.15	.13	4,905.74	.14	5,056.26	.14	4,657.67	.13
" pedestals, etc...	No.	9	2,531.74	480.00	2,700.00	300.00	2,774.57	308.00	2,606.31	488.00
" flash-boards.......	"	18	30.10	1.67	54.00	3.00	54.00	3.00	30.10	1.67
Div. chan., concrete......	C. Y.	8,570	38,326.47	4.45	68,600.08	8.00	96,523.02	11.24	66,249.41	7.70
" Cast-iron gates, 8×12	No.	5	16,334.84	3,267.00	18,500.00	3,700.00	18,862.40	3,772.00	16,697.24	3,340.00
" steel (complete).	Lbs.	67,008	3,823.91	.06	5,360.68	.08	5,884.28	.09	4,347.51	.064
Canal, steel.............	"	665	....	......	53.20	.08	53.20	......	....	......
Spillway forms..........	....	.....	....	......	1,200.00	......	1,200.00	......	....	......
Extra work............	....	.....	1,091.46	......	1,255.18	......	1,255.18	......	1,091.46	......
Totals.........................			370,477.35	......	443,941.08	......	509,743.98	......	436,280.25	......
Deduction, cement spoiled...........			....	......	60.45	......	60.45	......	....	......
Grand total.....................			370,477.35	......	443,880.63	......	509,683.53	......	436,280.25	......

Contract 17, Bates & Rogers Construction Company. Work begun November, 1904, finished September, 1906. Specification 12. Canal, 2,000 feet of North Canal and head-works included in this contract. Head-work gates, 9—5′ × 7′ cast iron.

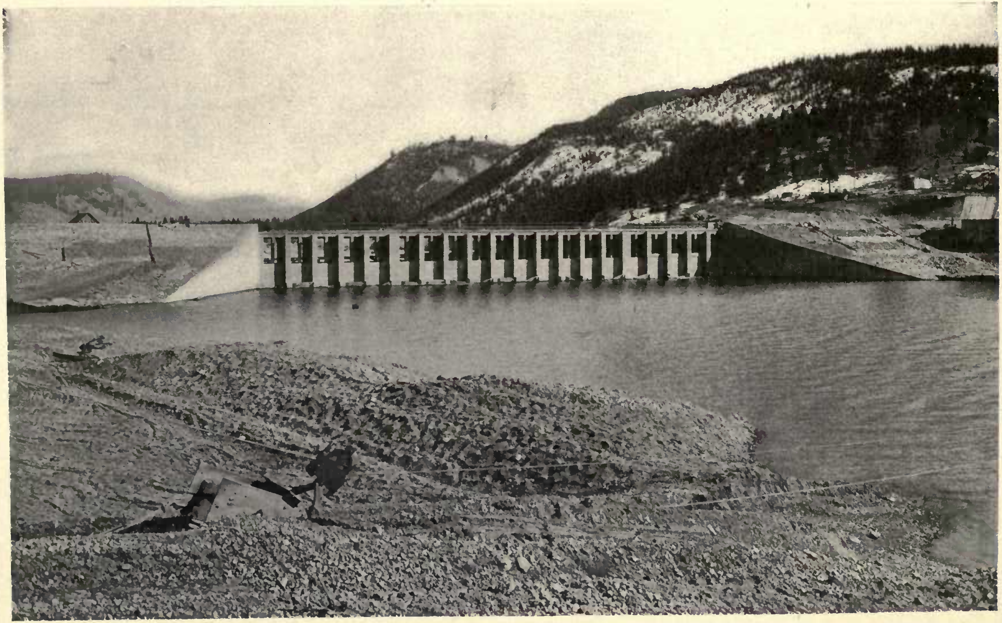


Fig. 49.—Jackson Lake Dam, Wyoming. Storage for Minidoka Project, Idaho.

In the spillway to the south of the dam were built a set of gates to permit the passage down-stream of the large quantity of water necessary for the irrigation of the north and south side Twin Falls Projects.

There are four radial gates built of steel on radii of 15 feet 3 inches, closing openings 12 feet high. Each gate has six radial spokes, three on each side, connected transversely by 12-inch channels. On the outside of these channels are riveted a number of 9-inch channels and I beams, curved to the radius of the gate, and spaced about 2½-feet centers. These curved members are covered with timber lagging bolted to the steel.

The gates revolve on 6-inch steel shafts, each shaft carrying half of two adjacent gates. Each gate therefore revolves on two shafts. The gates are anchored to and supported by concrete piers which separate adjacent gates, and are 3 feet thick and 20 feet high, its back being stepped on a slope of 1 to 1. The front is shod with a 6×6-inch angle, anchored to the concrete, and has a batter of 1 to 12.

The gates close on timber sills and the top and sides are sealed by rubber belting. They are operated by electric hoists. With the water in Lake Walcott standing at the lip of the spillway, these gates have a discharge capacity of about 5,000 cubic feet per second.

STORAGE SYSTEM

Lake Walcott is controlled within limits of about 6 feet of elevation, and this makes an available storage capacity of about 75,000 acre-feet, conveniently located at the head of both canals. To complete the storage system, a reservoir has been provided at Jackson Lake, on the Upper Water-shed of the South Fork of Snake River, where a controllable capacity of 380,000 acre-feet has been provided. The lake is very large, and the above capacity is obtained by raising the water only about 17 feet. The dam consists of a concrete sill and apron in the river channel surmounted by a series of 19 cast-iron gates between concrete abutments, and a long, low gravel dike connecting with high ground on each side. This reservoir has recently been enlarged to provide storage for the Twin Falls Projects.

THE HYDRO-ELECTRIC SYSTEM OF THE MINIDOKA PROJECT

The hydro-electric system consists of a power development at Minidoka Dam having a capacity of 10,000 horse-power, 31 miles of 33,000-volt, three-phase transmission line and three pumping stations where the power is used in raising water for the irrigation of nearly 48,000 acres of land. Power for general purposes is also supplied to the towns on the project.

Power-house.—The power-house building is of reinforced concrete, 149 feet long and 50 feet wide, and is built against the down-stream side of the concrete bulkhead in the diversion channel which had been cut through the rock for diverting the river during the construction of the dam. The up-stream wall is 19 feet above the top of the dam while the gables rise 95 feet above the bottom of the tail-race. The plant has been built with the idea of extending the building by running a wing from the north end at right angles to the present building, making it convenient to increase the capacity of the plant.

The buttresses of the concrete bulkhead are built on 18-foot centers, forming bays, in each of which is a 10-foot penstock opening. Five of these bays are utilized for the installation of the five 2,000-horse-power units of the present equipment, another bay contains the two exciter units and the two remaining bays included in the power-house will be required in case of future extensions.

Main Units.—Each of the main units consists of a 2,000-horse-power vertical turbine direct-connected to a 1,500-kilovolt-ampere alternator, designed to deliver three-phase, 60-cycle current at 2,300 volts. The turbines are of the vertical inward-flow axial-discharge type with 52½-inch runners operating under a normal gross head of 46 feet at a speed of 200 r.p.m. with a rated capacity of 2,000 horse-power. Each wheel receives its water from a 10-foot feeder, connecting with the corresponding penstock opening in the concrete dam and discharges through a curved draft tube into the tail-race. Admission of water to the runner is regulated by pivot gates under control of the governor and a motor-controlled sliding gate at the head of the feeder serves to cut the water out when the turbine is not in use. The turbines are placed on the lowest floor of the power-house, the center line

of the runners being 16 feet above normal surface of the water in the tail-race.

The generators are located on the main floor of the plant. They generate three-phase current at 2,300 volts and 60 cycles. The rotating element of the entire unit is suspended from a thrust bearing located on top of the generator. This bearing consists of two simple collars running in a water-cooled oil bath without pressure.

Each generator is provided with a governor which gets its oil pressure from a central oil system which is provided with a duplicate outfit of motor-driven gear oil pumps and pressure tanks.

Exciters.—Two exciters of 120-kilowatt rated capacity direct connected to turbines of 180 horse-power furnish 125-volt exciting current for the main generators. These units are each of sufficient capacity to excite all the five generators besides furnishing power for oil pumps. These units are also provided with oil pressure governors, and each has its individual governor system.

Transformers.—Each generator is provided with a three-phase air-blast transformer of 1,500-kilovolt-ampere capacity connected to the generator terminals by disconnecting switches, so that each generator and its transformer forms a unit receiving 2,300-volt current and delivering 33,000-volt current to the high-tension bus. The transformers are located in a gallery at the side of the generator room against the bulkhead.

A 20-ton Niles travelling crane runs the entire length of the generator floor within reach of all heavy apparatus.

Wiring Scheme.—All switching on the high-tension side of the transformers is accomplished by means of remote control oil circuit-breakers. A double 33,000-volt bus runs the entire length of the building above the transformer gallery and at the north end runs down through concrete compartments to the outgoing line switches on the generator floor.

From the line switches the circuit runs back through concrete ducts and up the north wall to the outlets. Aluminum cell electrolytic lightning arresters are placed on a gallery above the switchboard at the north end of the plant where the lines leave the station. Switches and outlets have been provided for both outgoing lines.

Switchboard.—The plant is controlled from a switchboard

located on an extension of the transformer gallery across the north end of the plant. This switchboard contains a panel for each generating unit and line, and one panel for the two exciters. All of the high-tension oil switches are controlled from this point and each generator panel is provided with devices for controlling the speed and voltage of the main units.

Panels and controllers for the penstock gates are placed on the generator floor near their respective units, and these controllers are to be used also for raising and lowering the sluicing gates which form a part of the original structure and are used to control the stored water in Lake Walcott at low stages of the river.

Transmission Line.—The transmission system comprises 38.4 miles of 33,000-volt line, which consists of a single circuit of copper wire run on wooden poles spaced approximately 150 feet apart, except the river crossings, which are on steel. The main line runs southwest from the dam, following the general direction of the main north side gravity canal and the Minidoka & Southwestern Railroad, to the Heyburn substation, a distance of 19 miles. From a point 10 miles from the dam a branch runs due south to pumping station No. 1, crossing the Snake River in a 1,150-foot span supported by steel towers. The poles on this part of the line are spaced 250 feet apart.

The second transmission line crosses the river near the dam and runs directly to the second pumping station, a distance of 11 miles.

PUMPING STATIONS

At the lower end of the south side gravity canal is located the first pumping plant, having a capacity of about 715 second-feet. A portion of this 715 second-feet is diverted for use in the "G" canal, which supplies an area of about 10,000 acres, while the remainder is elevated a second time at station No. 2. This station has a capacity of 640 second-feet. A portion of this water is diverted for use under the "H" canal, irrigating about 15,000 acres, while the remainder is again lifted at pumping station No. 3. This plant has a capacity of 395 second-feet and delivers water to the "J" canal, which supplies about 23,000 acres of land.

The lift at each station is about 31 feet, the average lift being about 64 feet.

The stations are of the same general design and a description of the first will in general apply to all. All the buildings are of reinforced concrete with roofs of the same material. The first is 140 feet long by 30 feet wide and 45 feet high. At the first station there are four 160-second-feet units and one 75-second-feet. Each pump is located in an independent concrete chamber 17 feet by 16 feet, protected by steel trash racks and steel gages. The pumps are of the vertical shaft type with both top and bottom suction. The impeller is 44 inches in diameter. When starting a unit the pit-gates are closed and the pit is pumped out, thus reducing the power required from the motors. When operating, the pump is submerged in the water. The discharge is controlled by means of a cylinder-gate between the impeller and the diffusion vanes. The unit operates at 300 r.p.m. The discharge of the pump is 48 inches in diameter, giving a discharge velocity of 10.4 feet per second at rated capacity. The casing of the pump is of cast iron. The vanes of the impeller are of steel plate with cast-iron shroud rings. The pumps discharge through a tapered casting into a reinforced-concrete pressure pipe, 5 feet 6 inches in diameter. At the discharge end each pipe is closed by a steel plate flap valve, which floats on the water when the pump is operating. The motive power for the pumping unit is furnished by a 600-horse-power, three-phase, synchronous motor, wound for 2,200 volts. When the units were first installed, it was deemed inadvisable to have these large pumps started at short intervals, as it was believed that the wave going down the canals would cause serious washing of the banks. Accordingly, a small one-second-foot pump was provided for emptying the pits. It took this pump about 40 minutes to empty a single pit, thus interposing a minimum interval of this amount between the starting of the pumps.

After the plants were operating, however, it was found that most of the interruptions in the power service were of momentary character and that the quicker the pumps could be gotten back on to the line, the more satisfactory the operation would be. In order to arrange for getting the pumps back on to the line in rapid succession, a discharge pipe with a valve has been fitted to the manhole of the pump and the pump is made to pump out its own pit. Under this arrangement, before a unit is started this valve is opened. Then the unit is started as before and the pit

is pumped out with the pump running at slow speed, the water being discharged into the forebay. As soon as the water level reaches the right stage, the unit speeds up and can be synchronized. This process requires only two minutes from the time the pump is started until it can be thrown on to the line ready for opening the pit-gates to begin pumping. The actual interval between the starting of successive pumps is about ten minutes, with one operator to perform all the work.

The transmission lines come into this pumping station through disconnecting switches to a single set of 30,000-volt bus-bars. From these bus-bars the current is carried through disconnecting and oil switches to five 500-kilowatt air-blast transformers which step the voltage down from 30,000 to 2,200 volts. These feed a common 2,200-volt set of bus-bars.

All heavy apparatus is under a 10-ton Niles crane which runs the entire length of the building.

Current is supplied to the motors by air-blast transformers, one 590-kilovolt-ampere transformer being provided for each pump. These transformers receive current at 30,000 volts from the high-tension bus and deliver it to the low-tension bus at 2,200 volts.

The wiring is so arranged that any one or all the transformers may be used with any motor.

Two induction motor-driven exciters, either of which is of sufficient capacity to excite all of the motors, are conveniently located close to the switchboard.

Aluminum-cell lightning arresters are provided for the protection of the station apparatus.

The switchboard, transformers and auxiliary apparatus are placed in one end of the building on a floor raised sufficiently to command a view of the entire motor end of the plant. The switchboard contains one panel for each motor and one for the two exciters, besides panels for the auxiliary apparatus.

All of the 2,200-volt switches are mechanically operated from this board, while the 30,000-volt switches which connect the transformers to the bus are placed near their respective transformers and each mechanically operated from a separate panel. There is a single high-tension bus and a single low-tension bus.

Low-lift Pumping.—A few small tracts occur in the project where it is necessary to lift the water from 3 to 5 feet to cover a few hundred acres. This is accomplished with scoop wheels

operated by electric power, and an efficiency of pumps averaging about 60 per cent is attained.

COMMERCIAL POWER SUBSTATIONS

Provision has been made for supplying power to distributing companies in Rupert, Heyburn and Burley. A transformer sta-

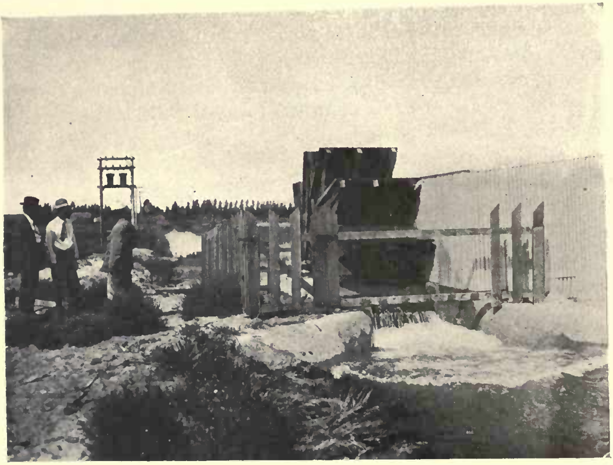


FIG. 50.—Scoop Wheel, Lifting Water 3½ feet, 60 per cent Efficient.

tion at Rupert will supply that town, and one on the Snake River near Heyburn will supply both Heyburn and Burley. These two substations are identical in design and are reinforced-concrete structures, approximately 20 by 30 feet in plan.

The stations are designed to receive power at 30,000 volts and deliver it to local distributing circuits at 2,200 volts. Each station is equipped with oil-cooled transformers protected by expulsion fuses. A switchboard panel controls the circuit for each town and lightning arresters are provided for both high- and low-tension circuits.

Original Cost of Pumping Stations

	No. 1	No. 2	No. 3
Excavation	$2,100	$5,300	$2,000
Building	35,000	40,000	19,500
Hydraulic machinery	27,200	23,000	16,200
Electrical machinery	44,700	42,800	17,300
Freight and hauling	10,300	9,600	5,500
Erection	15,800	14,600	9,300
Camp and permanent quarters	4,000	11,000	500
Engineering and incidentals	5,000	3,000	2,000
Administration charges, etc	8,500	7,000	5,500
Total	$152,600	$156,300	$77,800
Capacity—second-feet	575	500	325
Cost per second-feet capacity	$265.40	$312.60	$239.40
Pressure pipes including administration charges	21,400	16,500	20,200
Total length of pressure pipes—feet	894	540	825
Cost per foot	$23.90	$30.30	$24.50
Cost per second-foot capacity, including pressure pipes	303.00	346.00	301.00
Average		$318.00	

The efficiency of the apparatus is shown in the following tables:

	Full Load Efficiencies	Net Efficiency from Water Behind the Dam
Turbines	81.5	81.5
Generators	96.0	78.2
Step-up transformers	98.4	77.0
Transmission line	90.0	69.3
Step-down transformers	98.0	67.9
Motors	94.0	63.8
Pumps	72.5	46.3

Cost of Minidoka Electric Pumping System

Power plant and accessories	$ 484,427.69
Office, shop and storehouse	9,023.34
South side pumping stations	495,591.61
Gravity unit pumping stations	21,954.14
Transmission lines	74,226.56
Substations	43,149.22
Telephone system	29,082.07
Total	$1,157,454.63

Operation and Maintenance of Power and Pumping Systems

	Power-House	Trans-mission Line	Pumping Stations No. 1	Pumping Stations No. 2	Pumping Stations No. 3	Total
Operation—Labor	5,700	700	2,100	2,100	2,100	
Supplies	950	100	200	200	150	
Repairs—Labor	900	600	600	600	400	
Supplies and material	300	100	100	100	80	
Superintendence, clerical, camp, etc.	1,700	200	700	700	500	
General expense and administration	450	50	150	150	100	
Total operation expense	10,000	1,750	3,850	3,850	3,330	22,730
Operating expense per acre (48,000 acres)	$0.208	$0.037	$0.081	$0.081	$0.068	$0.475
Depreciation	21,700	3,400	7,600	7,800	3,900	44,400
Total	31,700	5,150	11,450	11,650	7,180	67,130
Annual cost per acre, including depreciation	$0.660	$0.108	$0.239	$0.243	$0.150	$1.40

Summary of Installation Costs

Power-house and accessories	$433,300
Transmission line	34,000
Pumping stations with pressure pipes	444,800
Total investment on power system	$912,100
Investment per acre (48,000 acres)	$19.00

Summary of Annual Charges

Operation	$ 22,730
Depreciation	44,400
Total	$67,130
Per acre (48,000 acres)	$1.40

CANAL SYSTEM

Gravity System.—The north side canal system on the Minidoka Project is rather unique in respect to the topography of the irrigated lands it serves. These lands have some local irregularities, but the tract as a whole is so flat as to present unusual difficulties to gravity irrigation. In order to provide the necessary slope to induce the irrigation water to flow out over the lands, it was necessary, first, to raise the water of the Snake River into the canals by means of a high diversion dam; second, to select the highest ridges available for locating the canals, and third, to

build the major portion of the canal system above ground between dikes built from borrow pits located outside the canal section.

There is so little slope to the valley that it was necessary to build the canals with a slope of only .0002, nor could any greater slope be given even to the laterals, which in consequence have a very low velocity and give some trouble in growing aquatic plants.

A large part of the irrigated land is sandy and in places underlaid by a coarse sandy subsoil. It is difficult to irrigate, without the use of an excessive quantity of water, on account of the losses into the subsoil. This has led to the deliberate application of a sufficient quantity of water to completely fill the subsoil and thus subirrigate the crops, or, as locally expressed, "bring up the sub." Some areas have applied 20 feet in depth in a single season.

This practice is not only very wasteful of water but tends to leach the plant food from the soil and ruins other lands by bringing the ground water to the surface and killing vegetation. Considerable areas were actually submerged until relieved by drainage ditches. The North Side Minidoka Project has thus been the location of the most extensive drainage works yet built by the Reclamation Service. These are described elsewhere.

The sandy soil composing the canal bottoms and banks has played an important part in adding to the ground water, and the losses from the canals, as well as the excessive demands, were found to tax the canal system to its utmost capacity when only about two-thirds of the land was irrigated.

Snake River usually carries clear water, and Lake Walcott serves as a settling basin for such silt as the occasional floods may carry, so that only clear water enters the canals, and thus there is no tendency to stop seepage from canals by silting. In order to reduce the canal seepage losses, a process of silting was resorted to, described hereafter, page 152.

Protection of Canal Banks Against Erosion.—In very sandy regions the banks of the canals are subject to wind erosion, sometimes to a disastrous extent. Small farm laterals cleaned out in the spring have sometimes been obliterated by severe winds, and considerable damage is often done to larger canals. Light soils are often seriously eroded by wave action, which occurs when high winds prevail.

The former trouble is sometimes remedied by blanketing the sandy banks with gravel or clay and by seeding them to rye, blue-grass, clover, or other vegetation. There is, however, a tendency for seed to blow away and it is difficult to get vegetation started under such conditions.

The erosion of canal banks by currents and wave action has been combated in several ways. Rock riprap has been much used, but is always costly and is not efficient unless laid in a very expensive manner. Unless the riprap is started below the canal bottom and the joints well plastered, it soon fails in sandy soil by the washing out of the sand between the cracks. Brush of any kind, weeds and grass will do temporarily, but the latter are good for but one season. Sage-brush is especially adapted to this purpose, being bushy, flexible, durable, and tough.

The method extensively used on the Minidoka Project is to plow a deep furrow in the bank about a foot below where the damage is likely to occur and smooth this out with a small V-shaped scraper which leaves a terrace about 2½ feet wide. On this a layer of brush is placed with butts to the bank and tops sloping toward the water down-stream at 30 or 40 degrees, the tops being kept in careful alignment. After the first row has been laid, another furrow is plowed higher up the bank and smoothed out with a scraper, pushing the dirt over the first layer and effectively binding it without the use of stakes. This process is repeated until the riprap is a foot above the maximum water surface. When finished, the tops of the brush should extend 8 inches beyond the earth they are buried in, but must not encroach upon the original canal section.

The distance vertically between layers of brush and the density of each layer should vary with the velocity of the water. For velocities below 3 feet per second, the density of the riprap may be about equal to that of the branches in the average sage-brush, and this should increase with higher velocities.

On the Minidoka Project a large amount of such riprapping was done at costs varying from 10 to 14 cents per square yard. During the silting process, the sage-brush riprap was very effective in collecting sediment.

In light soils, there is often a tendency to erosive action below checks or other structures in the canals, and deep holes are sometimes excavated in the canal bottoms below such structures.

These can be repaired cheaply with a sage-brush mattress, which must be deposited when the water is turned out of the canal.

The excavation is brought to even bottom about $2\frac{1}{2}$ feet deep and somewhat larger in area than the hole washed out. Stout stakes 4 feet long at 4-foot intervals are driven firmly into the bed of this excavation. At the down-stream end of the dip the sage-brush is placed butts down, leaning the tops down-stream about 30 degrees and packing them closely.

Galvanized wires are stretched across the brush, weaving it into the individual bushes, drawn tightly and fastened to each stake. As the mattress nears the structure, the brush should be less slanted, until at the structure it is vertical, and where the water impinges with greatest force it should be wedged in very tightly. After the mattress is made, the stakes should be driven down further, thus tightening the wires across the brush. Then the whole mattress should be puddled with mud and the side slopes of the canal riprapped with sage-brush.

Such work with occasional repairs is nearly permanent.

DRAINAGE

The more sandy, open soils allowed the irrigation water to pass freely to depths beyond the roots of the plants, and thus required very frequent wetting, and consumed a large quantity of water. The following table gives average depths of water used in one season for the various soils:

Sand	12	feet in depth
Sandy loam	8	" " "
Light sandy loam	4	" " "
Loam	2.5	" " "

The total range was, of course, much greater than this.

The difficulty of keeping the sandy ground sufficiently wet to keep young plants growing was very great, and led to efforts to fill the subsoil with water until the water table was raised to such a level that the plant roots could reach moisture. This was accomplished by running the water continuously through laterals at frequent intervals across the fields. The practice grew until it became prevalent over the sandier areas and some tracts of land received in one season sufficient water to cover them over 20 feet deep. This practice brought the water table to the surface over

large areas and killed all useful vegetation thereon. Several hundred acres were actually submerged with standing seepage water.

The water drawn from Lake Walcott was clear, and the flat country required canals of slight grade and low velocity. These conditions combined with the open soil caused heavy seepage losses from the canals and laterals through the sandy areas and these losses added to the extravagant use of water in "bringing up the sub" soon began to tax the canal capacity, and urgently called for remedy.

In 1913, it was decided to undertake the silting of the canals through the sandy reaches to reduce seepage losses. This was done by sluicing clay from a bank near the canal and spilling the water laden with finely divided clay into the canal from a flume. The water was pumped from the canal with a centrifugal pump and forced through a monitor for sluicing purposes. The clay settled in a thin layer over all the wetted perimeter and greatly improved seepage conditions.

Altogether, about 112,000 cubic yards of silt were sluiced into the canal, at a cost slightly over 20 cents per yard. As a result, the losses from the main canal were reduced from an average of 110 cubic feet per second in 1912 to 71 second-feet in 1915, a reduction of 35.5 per cent of the total losses. Large reduction in losses from the lateral system was also effected.

A number of incidental benefits have resulted from the silting, besides the saving of water and partial relief from water-logging. Some of the clay passed out on the sandy lands in the process of irrigation and greatly improved it by making it less pervious. To obtain the full benefit of this, deep plowing and thorough harrowing are necessary. In some of the laterals, the deposit of clay was excessive and cleaning was required. The clay placed on the sandy banks of these laterals gave a coating that stopped the wind erosion that had given much trouble by destroying the banks and filling ditches.

The topography of the north side of Snake River on the Minidoka Project, comprising 70,000 acres, was almost flat except for minor local inequalities, and contained practically no drainage lines. Storm water had no escape except through the subsoil, and in a few places formed ponds in wet seasons. The advent of irrigation, with its excessive application of water, increased the number and permanency of these ponds and gradually the ground

water rose over large areas until, in 1912, 506 farms were affected and nearly 7,000 acres of land were damaged.

A complete system of main drains was planned in 1910 and about 108 miles of open drains have been built at a total cost of about $622,000 or about $1.09 per foot. Most of the work was done by Government forces with two large drag-line scrapers with electrical equipment, the motive power being furnished by the hydroelectric plant at the diversion dam. A suction dredge was employed on part of the work, and a small part was done with teams. The work done with the large drag-lines averaged about 10 cents per cubic yard, exclusive of overhead and general expenses, the contract work with teams ranging from 12.2 cents for earth and 34 cents for hardpan to $2 per yard for rock, of which the quantity was small.

The drains discharged a maximum of 229 second-feet in the summer of 1915. The cost of maintaining these drains ranges from $30 to $40 per mile per annum. They have effected a practically complete cure of the seepage conditions, only 400 acres remaining to be reached by short branch drains.

Incidentally these drains furnish an abundance of good stock water through the winter, much warmer and therefore better than canal water, and this has proved an important stimulus to the winter feeding of stock and greatly promoted the prosperity of the farmers.

WATER DELIVERY

On the north side or gravity unit of the Minidoka Project water is delivered to each lateral continuously during the irrigation season. In some cases the irrigators under one lateral rotate among themselves, using a head of 1 second-foot or less. On the south side or pumping unit a rotation head of from 1 to 2 second-feet is used, and is delivered continuously to each 160-acre tract in crop. Eighty acres in crop receive a rotation head eight days in every sixteen. Forty acres in crop receive a rotation head four days in every sixteen, but intervals between deliveries never exceed eight days. Modifications of delivery dates may be mutually arranged between water users.

The gravity portion of the Minidoka Project was mainly built by F. C. Horn, under the general direction of D. W. Ross, Supervising Engineer. The power and pumping plants were designed and built under the direction of O. H. Ensign.

CHAPTER IX

HUNTLEY PROJECT

DESCRIPTION

The Yellowstone River is one of the few in the West which presented to the Reclamation Service an opportunity for diversion of water upon irrigable land without the necessity of storage. Water is diverted on the right bank of Yellowstone River about 12 miles east of Billings, Montana, and carried through a series of tunnels and heavy cuts to cover about 28,900 acres of irrigable land.

The head-works consist of a reinforced-concrete structure provided with two steel gates, each 5 × 7 feet, installed parallel to the river bank, and designed to divert water from Yellowstone River without the employment of a weir.

CANAL SYSTEM

The Northern Pacific Railway occupies the right bank of the river in this locality, and it was found necessary to carry the canal under it at the head-works, and to construct a series of tunnels and heavy cuts as a conduit parallel to the railway, leaving ample space for double-tracking the railway in future.

After passing under the railroad, the water enters tunnel No. 1, which is 700 feet long, and thence passes through a rock cut to tunnel No. 2, which has a length of 1,550 feet, and later through tunnel No. 3, 400 feet in length. These tunnels are lined with concrete and are 9.2 feet wide and 9 feet high at the center of the arch. The channel changes from cut to tunnel by means of warped surfaces in each case. The rated capacity is 400 cubic feet per second. At the entrance of tunnel No. 3, about 11,000 feet from the head-gate, is a heavy reinforced-concrete structure used as a wasteway during low water, and at flood stages may be employed as an intake.

The canal location crosses the original channel of Pryor Creek

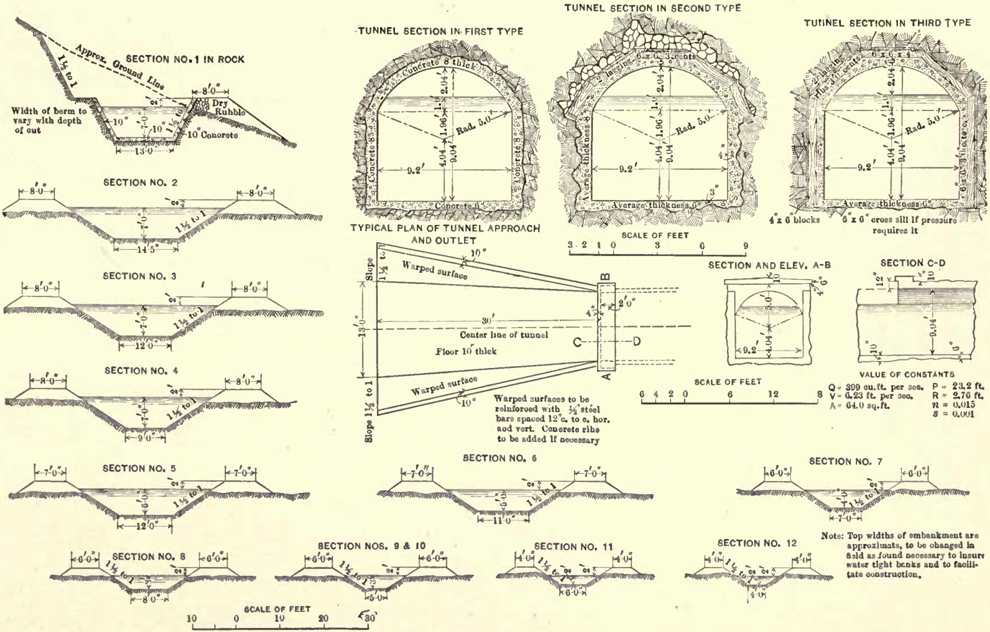


FIG. 51.—Sections of Canal and Tunnels, Huntley Project, Montana.

eight times. To eliminate these crossings, the creek was diverted to the left, into an artificial channel, and a reinforced-concrete structure carries the flood waters of the creek over the canal in a sort of flume, and discharges them under the Northern Pacific Railroad tracks into the river. After passing through a heavy gravel cut, the canal emerges upon the irrigable land a short distance east of Huntley.

About 12 miles further east, near the town of Ballantyne, an economical location requires the main canal to drop to a lower level, where a fall of 34 feet is utilized to generate power by which 50 cubic feet of water per second is pumped to a bench 45 feet higher than the main canal, and covers about 3,000 acres of land on that bench east of Ballantyne. The pumping plant is in two units, each with a capacity of 28 cubic feet per second and each consisting of a 20-inch centrifugal pump actuated by a vertical turbine on the same shaft, the whole unit being enclosed in a steel cylinder. The weight of the moving parts is carried on a film of water under pressure from the force pipe. An automatic alarm gives warning of any failure of the system of water lubrication. These direct-pumping units are automatic, requiring no attendance except to keep trash away and to see that nothing goes wrong with the lubrication.

Cross drainage was taken care of by culverts when the drainage line was small and the grade was suitable. Some of the larger torrents were carried over the canal in superpassages. An important example of the latter class is the structure built to carry the Custer Coulée across the canal. This coulée drains an area of about 7 square miles above the canal, and a superpassage was designed for a capacity of 500 cubic feet per second. The water is backed up in the channel to a depth of 8.5 feet above the bottom of the coulée to reach the rated discharge. The flume is designed to serve also as a bridge when not carrying water. Fig. 55 shows a view of this structure.

Cost of Main and High Line Canals

Dry excavation,	earth,	755,924	cu. yds. at	$0.24	$181,472
" "	loose rock,	8,227	" "	.57	4,698
" "	rock,	13,093	" "	1.23	16,097
Wet "	earth,	10,773	" "	.72	7,718
" "	rock,	6,702	" "	2.97	19,913
Overhaul, 149,544 station yards			"	.0175	2,615
Total excavation					$232,513

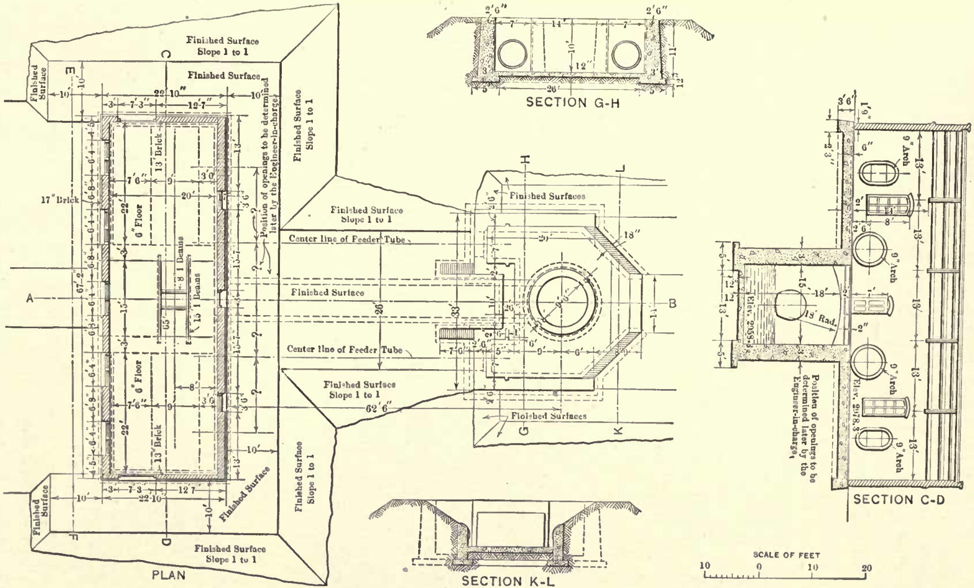


FIG. 52.—Plan and Sections, Direct Pumping Station, Huntley Project, Montana.

Cost of Main and High Line Canals—*Continued*

Head-works:	
Reinforced concrete, 186 cu. yds. at $17.57	$3,268
Gates and guides, and placing, 4,328 lbs. at 24 cents	1,040
Two stands and shafts, at $302.50	605
Total head-works	$4,913
Canal lining, 826.2 cu. yds. at $10	$ 8,262
Tunnel No. 1, 724 lin. ft. at $46.14	33,405
Concrete in portals, 74.6 cu. yds. at $17.47	1,304
Tunnel No. 2, 1,545 lin. ft. at $44.22	68,332
Concrete in portals, 163 cu. yds. at $17.46	2,844
Wasteway, concrete, 338 cu. yds. at $18.50	6,250
Gates and guides, and placing, 4,328 lbs. at 24 cents	1,043
Two shafts and gate stands at $303.50	607
Tunnel No. 3, 385 lin. ft. at $44	16,940
Concrete in portals, 74.6 cu. yds. at $17.42	1,300
Reinforced-concrete culvert under Pryor Creek	8,620
Rectification of Pryor Creek	19,298
Two steel-truss highway bridges across main canal and Pryor Creek	5,226
Two reinforced-concrete culverts to carry main canal under railroad	9,086
Reinforced-concrete culvert to carry high line under railroad	2,690
Concrete flume to carry Custer Coulée over main canal	2,884
Seven concrete drain culverts under main canal	21,816
Reinforced-concrete flume to carry drainage over canal	4,542
Concrete culvert and wasteway at Arrow Creek	10,891
Second drop and diffusion chamber	11,140
Concrete pressure pipe under Fly Creek	4,440
Three reinforced-concrete drainage culverts	5,723
Thirty-nine vitrified pipe culverts	6,526
Railroad bridges and culverts	4,615
Real estate	651
Total main and high line canals	$495,862

Cost of Direct-Pumping Plant

Excavation, 22,666 cu. yds. at 81 cents	$ 18,468
Concrete, 17,592 cu. yds. at $20	35,184
Puddling and paving	250
Two vertical-shaft direct-pumping units at $3,800	7,600
Two steel draft tubes, 12,750 lbs. at 12 cents	1,530
Two steel intake pipes, 17,038 lbs. at 12 cents	2,044
Two gate valves for discharge pipes, 6,430 lbs. at 14 cents	900
Piping, 20,200 lbs. at 11 cents	2,222
Traveller, truck, trolley and chain block	1,100
Two head-gates and frames, $1,112 each	2,224
Total pumping plant	$ 71,522
Cost of Distributing System	$238,125
28,805 acres served at $8.26 per acre.	

AGRICULTURAL RESULTS

The lands of the Huntley Project were formerly a part of the Crow Indian Reservation. By Act of Congress, approved April 27, 1904, a portion of the reservation lands, including the Huntley Project, were made subject to reservation and disposition under

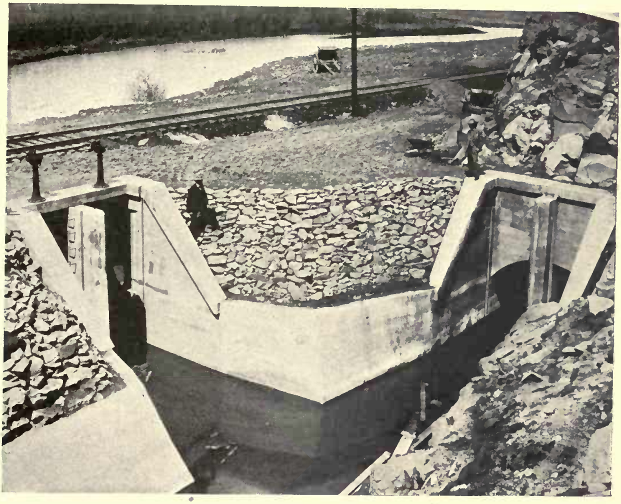


FIG. 53.—Waste-gates and Portal of Tunnel No. 3, Huntley Project.

the terms of the Reclamation Act, in conjunction with the construction of irrigation works so far as feasible projects occurred. Under the provisions of this act, the lands to be irrigated under the Huntley Project were withheld from settlement until the works were constructed and the water ready for delivery. They were then opened to homestead entry in units of 40 acres, and one installment of the building charge was required at time of entry. The service by thus having a free hand obtained settlers when wanted, secured a small farm unit, and a class of settlers having a "stake" in the land by reason of making a substantial payment in advance.

The result has been one of the most successful projects the Service has opened. The building charge is $30 per acre, in addition to which the settler must pay the operation and maintenance charge of about 75 cents per acre per annum, and $1 per acre per annum for the land for the benefit of the Indians

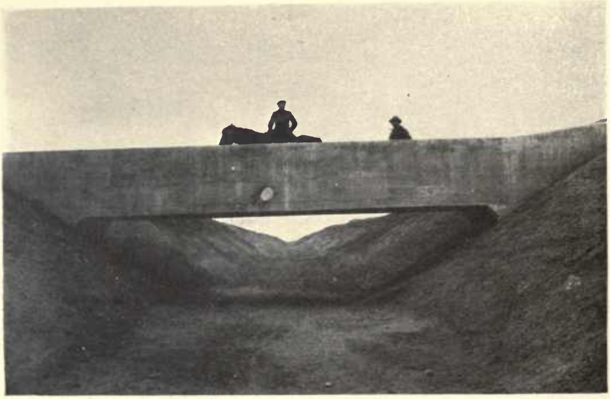


FIG. 54.—Concrete Flume over Huntley Main Canal.

until this amounts to $4. Notwithstanding these charges and the cold climate, very few cases of delinquency have occurred, and general deferment of collections or graduation of payments has never been requested. Some cases of hard struggles have occurred where settlers were unfortunate or possessed insufficient capital, but only three entries have been cancelled for non-payment.

DRAINAGE

In parts of the Huntley Project the soil is very gravelly and open, and in such places the losses from the canals are considerable, and large quantities of water are used in irrigation and escape into the subsoil. In other localities the soil is of a heavy-clay character, and the processes of irrigation have led to the rise of ground water on a part of the project to an extent to require the inauguration of drainage works to relieve the waterlogged condition threatened in some places.

A large mileage of open drains have been built, and 27 miles of tiling have been laid underground. These measures have had satisfactory results in relieving the conditions where they were applied. In a few cases seepage conditions were improved by lining short reaches of the canals with concrete in gravelly

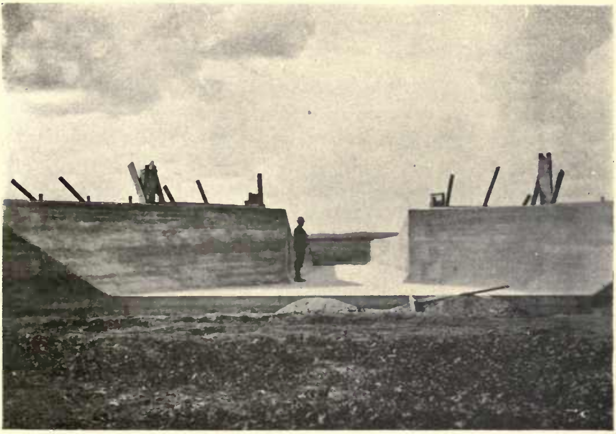


FIG. 55.—Superpassage of Custer Coulée, Huntley Project, Montana.

places. At this writing, 1916, the service has built on the Huntley Project about 6 miles of open drains at an average cost of $2,000 per mile, and 27 miles of tile drains, mostly 12 and 15 inches internal diameter, at an average cost of $8,750 per mile, involving a total cost for drainage of about $248,000, which is a little over $20 per acre for the land relieved by the works.

WATER DELIVERY

Water is delivered on the Huntley Project by rotation. Each irrigator receives double the average quantity to which he is entitled for a period of four days, and for the next four days receives none. This system is made elastic and provides for variation as desired by the users so far as this does not interfere with the regular delivery to others, and considerable exchange of

delivery between irrigators takes place. The system gives entire satisfaction.

The Huntley Project was mainly designed and built under the direction of H. N. Savage. The pumping plant was designed and built under the direction of O. H. Ensign.

CHAPTER X

LOWER YELLOWSTONE PROJECT

DESCRIPTION

Montana and North Dakota were both States from which the receipts from the sale of public lands were large, the latter leading the list for several years. Under the provision of the Reclamation Law, providing for the expenditure of the money within the State in which it was received, it became necessary, in order to make these funds available, to find a project for construction that would irrigate land in North Dakota. Reconnaissance for this purpose was begun in 1902, soon after the passage of the act, but without success.

In 1903, the investigations were extended into the Yellowstone Valley, and it was found to be possible to divert the waters of Yellowstone River near the town of Glendive, Montana, into a canal on the north side of the river, and irrigate a large acreage lying partly in Montana and partly in North Dakota. In the following year the surveys were considered on the ground by a Board of Engineers and a diversion point selected about 18 miles below Glendive.

The project provides for the diversion of water on the north side of the river into a canal with a capacity of 800 cubic feet per second, which extends down the valley about 66 miles to the Missouri River and covers about 66,000 acres of land. At a point about 19 miles below the head of the canal where it is necessary to drop a portion of the water to a lower level the energy of the falling water is to be utilized to lift water to a higher level for the irrigation of about 3,000 acres lying above the main canal.

MAIN CANAL

The head-gates for the main canal, eleven in number, are set in a high, massive, reinforced-concrete structure, built to an elevation above high-water mark, and containing 4,882 cubic yards of

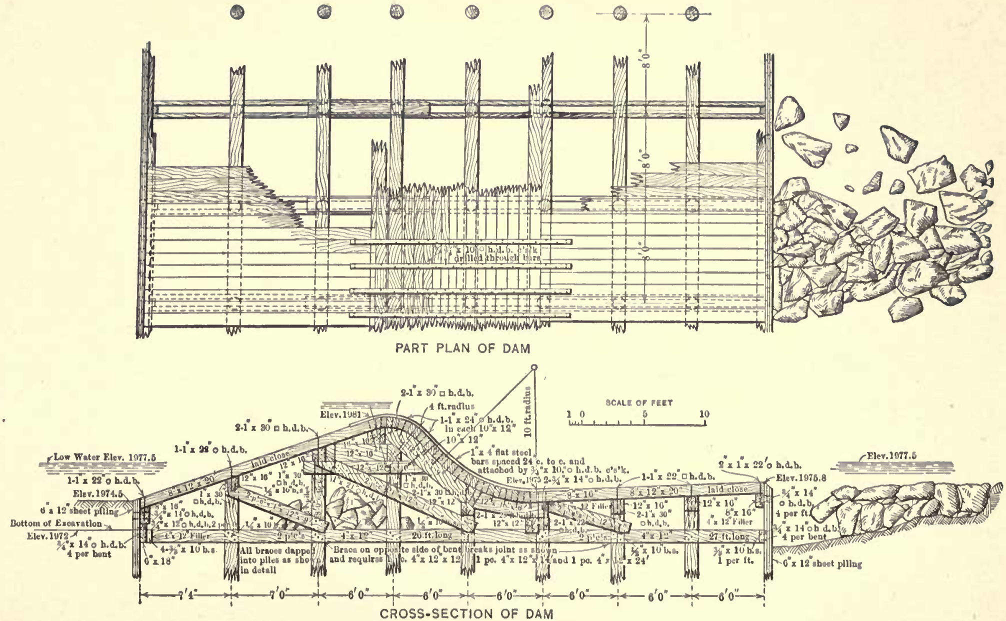


FIG. 56.—Lower Yellowstone Diversion Dam, Yellowstone River, Montana.

concrete and 45,000 pounds of steel. The structure is protected from the impact of ice by a sheathing of heavy pine timbers which are easily renewable. The designs are shown in Fig. 56.

Several important structures in connection with this canal were necessary to care for the cross drainage lines. The first of these is Linden Creek, which is carried across the canal in a superpassage, consisting of a reinforced-concrete flume 12 feet wide, 8 feet 6 inches deep, and 152 feet long.

At Burns Creek, 8 miles below the heading, are provided two sluice-gates set below the grade of the canal, each 5×12 feet. The waters of the creek are carried in a channel 100 feet wide under which the canal waters are carried in two conduits each $9 \times 10\frac{1}{2}$ feet. The design of this structure is shown on Fig. 59.

Fox Creek, 36 miles below the head-works, is the largest stream crossed. The canal is carried under the channel of the creek in a reinforced-concrete pressure conduit or inverted siphon 225 feet long, with two barrels, each 7 feet in diameter, at the head of which is a sluiceway having two gates, each 5×5 feet.

Low-water period on the Yellowstone River is from August 15 to May 1 of the next year, interrupted for a short period, usually in March, when the ice breaks up and is usually accompanied by violent freshets. The regular high-water period occurs between May 15 and August 15, due to melting snow in the mountains.

Ordinary low water is about 6,000 cubic feet per second, and extremely high water about 160,000, which carries large quantities of drift, mostly submerged.

The river bottom was mostly coarse gravel, underlaid with tough blue clay, irregularly mixed with sand, which was practically water-tight, very hard and firm in places, but easily eroded in others. The gravel cover varied in thickness from zero to a maximum of 11 feet. The clay extended to an unknown depth.

DIVERSION DAM

The diversion dam is a rock-filled pile weir decked with timber 700 feet long and 50 feet 4 inches wide, with an average height above river-bed of about 9 feet. It raises the water about 4 feet

above natural low water into a canal on the north bank. The design of the dam is shown on Plate 56.

A contract was let for its construction in 1906, and work was started in 1907. Flood conditions and the cold climate made it

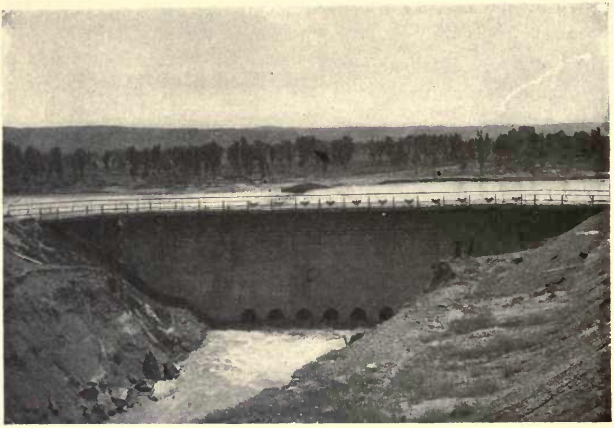


FIG. 57.—Head-gates and Dam, Lower Yellowstone Main Canal.

necessary to plan construction work with care and skill and to carry out the plans with energy and precision. It was the contractor's plan to drive the round piles in the spring of 1907, before the summer floods, and to complete the dam after the flood had subsided. This was defeated by the difficulty of procuring piles, and work was postponed till 1908, and the driving of permanent round piles was begun in April of that year, and 480 such piles had been driven when work was stopped by high water, on May 20, and could not be resumed until August 3. When the summer flood had subsided, efforts were made to drive the sheet piling required, which was of the Wakefield type, built of three planks each. It was found after thorough trial that because of their length and flexibility, and the hardness of the bottom, such piles invariably failed before reaching a satisfactory penetration. A similar result followed trials with four-ply piles of the same

type, both with a steam hammer and a drop hammer. It was accordingly found necessary to change the type of sheet piling.

An examination in August, 1908, showed that the driving of the round piles by the contractor previous to the summer flood had been a great mistake. The high velocities of the flood season, aggravated by the accumulation of drift against the piles, had caused great erosion of the river-bed, and had taken out a number of the round piles and left others with scant penetration. These various delays and difficulties discouraged the contractor and on September 14, 1908, he refused to proceed further under the contract, which was accordingly suspended and the work undertaken by Government forces. So much of the low-water period had been lost, and the material and equipment on hand were so incomplete, that it was deemed imprudent to attempt to complete the dam before next high water, and most of the round piles already driven were pulled.

It was decided to complete 62 linear feet of the dam adjacent to the south abutment, to remove the plant and lumber to high ground for safety, and then await the next low-water season.

The 62-foot section was completed by December 31, 1908, by J. W. Martin, who soon after resigned, and was later succeeded by Joseph Wright.

No further construction work being practicable till after the summer flood had passed, the spring and early summer were occupied in assembling material and equipment and the construction of adequate camp and construction plant. An examination of the river-bed showed that the greater part of the erosion which had occurred in 1908 had been refilled with gravel during the floods of 1909.

The river having sufficiently subsided by August 13, active construction was started on that date and pushed with all possible speed, 24 hours per day and 7 days per week. Instead of the Wakefield sheet piling, resort was had to solid timbers of Douglas fir, 10 × 10 inches, sharpened and shod, and with strips of 3 × 4 inches spiked on in such positions as serve for tongue and groove. These were found to have far greater rigidity and endurance than the Wakefield piling. Where the ground was too hard for satisfactory penetration by these piles, a steel shape, built of riveted steel about the size of the pile, was first driven and after-

ward withdrawn, and the pile driven in its place. Where the ground was too hard for this process, plain steel sheet piling was driven, but in most locations the wooden piles were used.

The cofferdam was constructed by allowing the sheet piles, which constitute the upper and lower curtain walls of the dam, to project well above water surface and banking them with gravel. To prevent scour of the open section of the river while the first two sections of the dam were being constructed, the river bottom was blanketed with large stone and much of the apron stone below the dam was placed, care being taken to keep the stone out of the line to be occupied by the sheet piling. This effectually protected the bottom from erosion, but before it could be placed a very unusual rise in the river occurred in September, which caused heavy scour around the ends of the cofferdam. This was combated and finally controlled by means of sacks filled with gravel and by dumping rock in the area threatened with erosion. The last section of the dam was closed by depositing sufficient large stone to raise the water over the completed section of the dam, and thus reduce the head and the current sufficiently to permit the construction of the pile cofferdam.

The dam proper was completed ready for wrecking the last cofferdam, January 29, 1910, and the work finished a few weeks later.

Shortly after the completion of the dam, on March 4, the ice broke up and passed down the river with customary violence, but soundings made in the following season of low water revealed no damage to the dam.

The ice-run of March, 1911, was unusually severe, and a great deal of pounding of ice masses on the apron of the dam was seen and heard. The severity of this run was due to a succession of ice-jams which broke suddenly and sent vast masses of ice down the river at high velocities. Examination of the dam after this run showed that much of the loose stone below the dam had been moved down-stream and that some erosion had occurred along the lower side of the down-stream row of sheet piling. No repairs were made that spring, however.

In November, a more thorough examination showed that the lower row of sheet piling, for a distance of about 500 feet, had been cut off by the ice or otherwise broken and that a portion of the timber deck was gone. Serious erosion had also taken place at

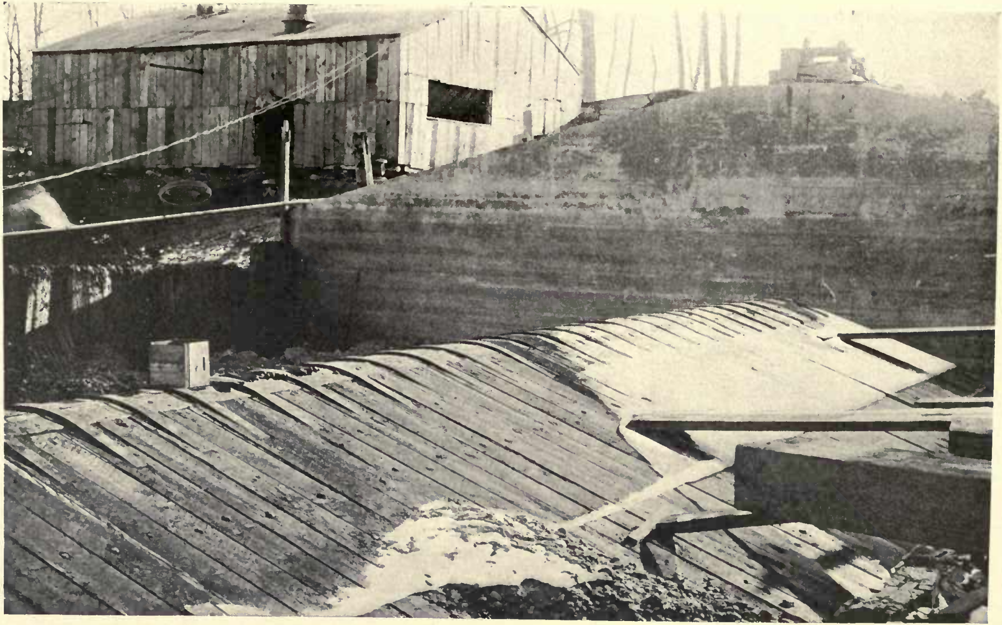


FIG. 58.—Southside Abutment, Lower Yellowstone Dam, with portion of Main Dam.

several points in the body of the dam, and a large amount of rock removed from the section where the deck was gone.

It was found that where steel piling had been driven it had successfully resisted the pounding of the ice, and it was therefore decided to employ steel in place of the wooden sheet piling that had been sheared or battered off by the ice. A cableway was installed over the dam site to facilitate repairs and rock was placed in the dam to the amount of about 6,000 cubic yards, and about the same amount was placed below the dam to protect the toe from erosion. The deck of the injured portion was restored. Notwithstanding the severe winter, the repairs were completed on February 17, 1912, before the ice run of that year. The dam has ever since given satisfactory service without material repairs.

SUMMARY OF COSTS, LOWER YELLOWSTONE PROJECT

Diversion dam	$ 331,917
Main canal	2,003,080
Lateral system	263,509
Highway bridges	75,357
Real estate rights and property	29,137
Buildings	18,162
Telephone system	23,717
Survey of irrigable lands	15,357
Examination of project as a whole	50,453
Total construction cost	$2,810,689

AGRICULTURAL RESULTS

The water supply from the Lower Yellowstone River is unfailing, the works for its diversion and delivery are effective and satisfactory, the soil is productive, and the climate favorable for agriculture, but the agricultural results from the Lower Yellowstone Project are disappointing. This is due entirely to the failure or refusal on the part of the majority of the land owners to use the water in irrigation. The location of the project is in the semi-arid region, where some seasons occur when the rainfall is sufficient for most crops, and in nearly half the years enough rain falls to secure fair crops of some kind. It can easily be demonstrated that irrigation would pay well in the long run, but each year the average farmer hopes for favorable rains, and prefers to take the chance of nature to assuming the certainty of his

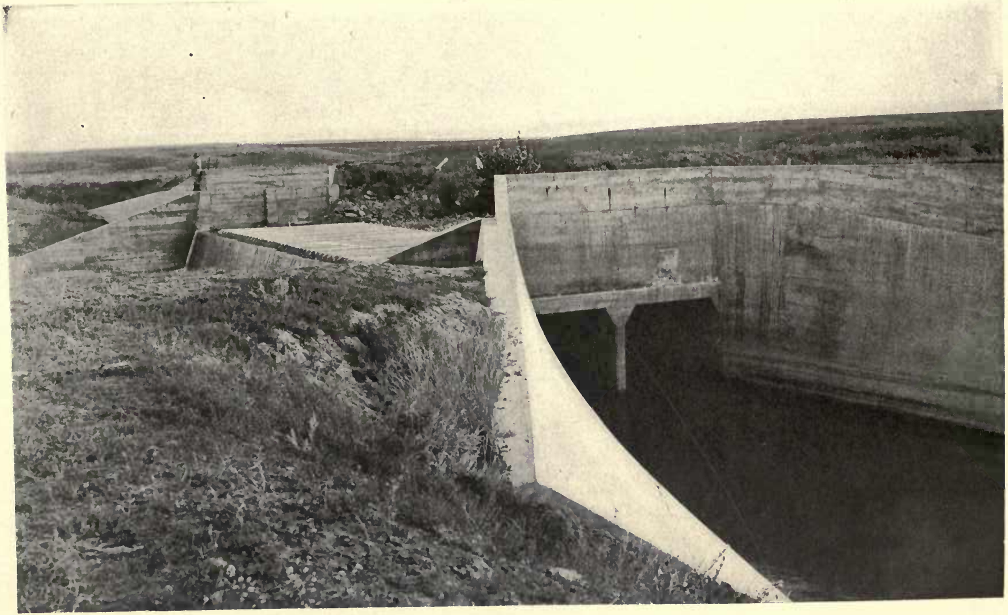


Fig. 59.—Burns Creek Superpassage, Lower Yellowstone Canal, Montana.

water payments. The following table shows the relation of the irrigated area to the area for which the Service was prepared to supply water.

IRRIGATED AREAS, LOWER YELLOWSTONE PROJECT

	1910	1911	1912	1913	1914	1915
Acreage for which Service was prepared to supply water	40,133	37,867	37,880	37,799	36,250	36,250
Acreage irrigated	8,655	15,445	5,068	7,660	5,743	5,765

The Lower Yellowstone Project is an excellent illustration of the psychological phenomena above described, which is illustrated

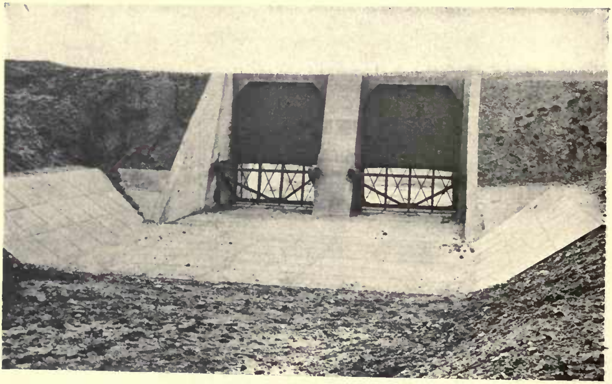


FIG. 60.—Outlet End of Crane Creek Sluiceway, showing Taintor Gates.

also by numerous canals which were built in Kansas, Nebraska, and the Dakotas, and though much needed at times, the seasons are such as to stimulate the immortal hope for favorable rains, and the canals were allowed to fall into disrepair and were abandoned.

The Lower Yellowstone Project was designed and built by F. E. Weymouth, under the general direction of H. N. Savage, Supervising Engineer, with A. J. Wiley as Consulting Engineer.

CHAPTER XI

NORTH PLATTE PROJECT

DESCRIPTION

In the North Platte Valley in Wyoming and Nebraska is one of the largest and most comprehensive reclamation projects in the United States. When the United States entered this field, a large number of small canals had been built in the valley, most of them in Nebraska, and the unregulated water supply was so far over-appropriated that in the autumn of years of low run-off the river was nearly dry, even at the State line, and in all normal years most of the canals in Nebraska were short of water in the late summer.

The Government investigations therefore began with a search for reservoir sites. One on the Sweetwater, a tributary of the main stream, previously recommended, was found to have unfavorable foundation conditions and deficient water supply. A site was found, however, on the North Platte itself about 3 miles below the mouth of the Sweetwater, where a reservoir, known as the Pathfinder, was constructed with a capacity of 1,100,000 acre-feet, a magnitude sufficient to provide storage for irrigation purposes of all the unappropriated supply of normal years and to hold a large reserve from the years of heavy run-off for use in years of drouth.

These waters are diverted by a concrete dam near Whalen, Wyoming, into a canal on the north side of the river called the Interstate Canal, supplying lands in both Wyoming and Nebraska. Provision is also made at this dam for a canal on the south side called the Fort Laramie Canal.

INTERSTATE CANAL

The Interstate Canal has a capacity at its head for about 1,300 cubic feet of water per second, which is used directly in irrigation of the lands under it, and its entire supply is needed for

such lands in summer. In the spring and autumn, when less water is used, the surplus capacity is employed to convey water to a series of small reservoirs that have been constructed in the valley, beginning about 100 miles below the head-works of the canal.

The first of these reservoirs, called Lake Alice, has a capacity of 14,000 acre-feet, and was placed in service in 1913. The largest, first used in 1915, is called Lake Minitare, and has a capacity of about 67,000 acre-feet.

These reservoirs enable the main canal to bring water to a much larger area than it could otherwise supply, and also furnish valuable insurance to the lands under them, which otherwise would be left without a supply in the event of a break in the canal, the liability to which increases with its length. Lake Alice is nearly 100 miles from the head of the canal, and Lake Minitare is 12 miles still further east.

PATHFINDER DAM

The Pathfinder Dam is built of granite random rubble masonry with coursed rubble faces. It is curved to a radius of 150 feet, has a total length of 432 feet, a height of 218 feet above lowest foundation, a top width of 10 feet, an up-stream batter of 15 per cent and a down-stream batter of 25 per cent. It is located about 3 miles below the junction of the North Platte and Sweetwater Rivers, where the canyon is about 90 feet wide at the bottom and 200 feet wide at the top, the sides for the upper 75 feet being nearly vertical. The depth from the top of the canyon to bed-rock in the foundation is about 200 feet. Above this canyon the valleys of both streams widen out and form a reservoir site of large capacity. The site is called the "Pathfinder," on account of a tradition that Gen. John C. Frémont, popularly known as "The Pathfinder," passed through this canyon on one of his exploring trips.

Pathfinder Tunnel.—To divert the flow of the river during the construction of the dam, and to serve as an outlet for the reservoir after its completion, a tunnel was driven by contract through the northerly abutment of the dam, and was provided with gates of large capacity to regulate the outflow.

Preliminary Work.—Bids for the construction of the dam were

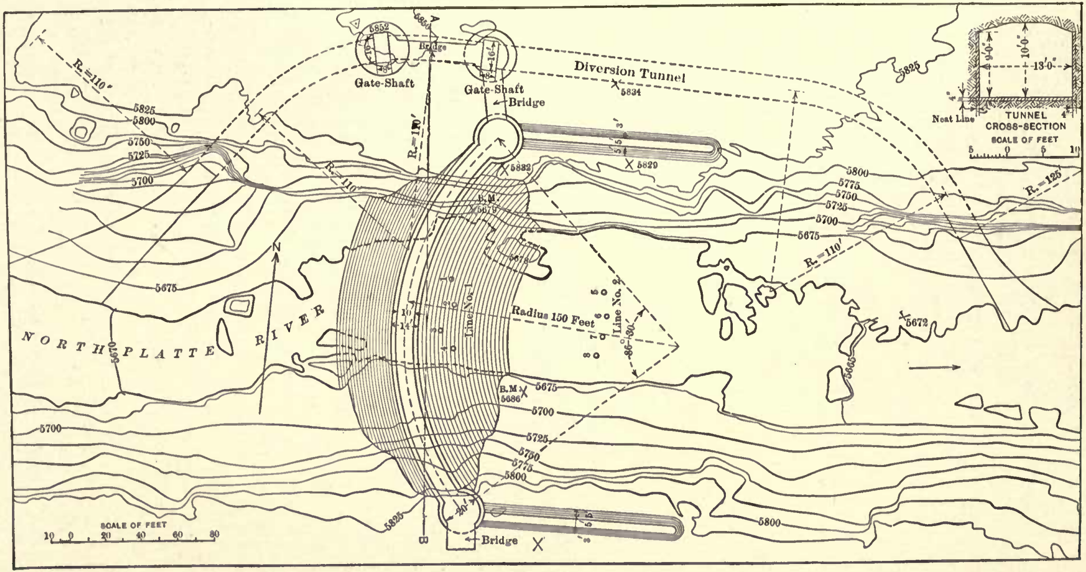


FIG. 61.—Plan of Pathfinder Dam, North Platte River, Wyoming.

opened June 15, 1905, and the contract was soon after awarded to the lowest bidder. During the latter part of June the contractors went to the dam site, decided that their price was too low, and failed to qualify. The delay incident to the necessity of readvertising was unfortunate, as it threw the preliminary construction work into the winter.

Bids were again opened August 16 and the contract awarded September 1, 1905. By the middle of the month a temporary camp was established; in November sufficient plant had been received to allow actual construction work to begin. The contractor endeavored to obtain a diversion dam by blasting loose rock from the upper canyon walls. Hundreds of tons of rock were thus blasted off, but the rock did not fall where intended, and the river bottom, for a large area, was covered with large stones, the crevices between which it was impossible to fill and the loose rock forming an immense subdrain, which later gave some trouble.

On this foundation, large quantities of rock, gravel, and earth were placed with derricks; gravel and earth were dumped over the upper face to tighten the dam, but most of it washed through. To add to the difficulty, the weather was extremely cold, the rock was coated with ice, and it seemed impossible to tighten the dam by dumping material above it. However, by building other dams below it, in steps, each dam going deeper than the one above it, the water was eventually controlled sufficiently so that the leakage could usually be taken care of by a flume 2.5×2.5 and three 6-inch centrifugal pumps. The auxiliary dams were made of sandbags backed with earth and gravel. The flume was built from the lower dam, across the site of the foundation and terminated at a second cofferdam built below the dam site to prevent backwater flooding it.

Excavation.—Early in January, 1906, excavation for the foundation was commenced. The cold weather delayed operations and added to the cost of this portion of the work. In addition to the sand, gravel, and boulders, it was necessary to excavate large quantities of ice, and during the coldest weather, far below zero, ice had to be removed every morning. Five guy derricks were so placed that every part of the area to be excavated could be reached. Rock suitable for use in the dam was laid aside and other material was dumped outside the temporary

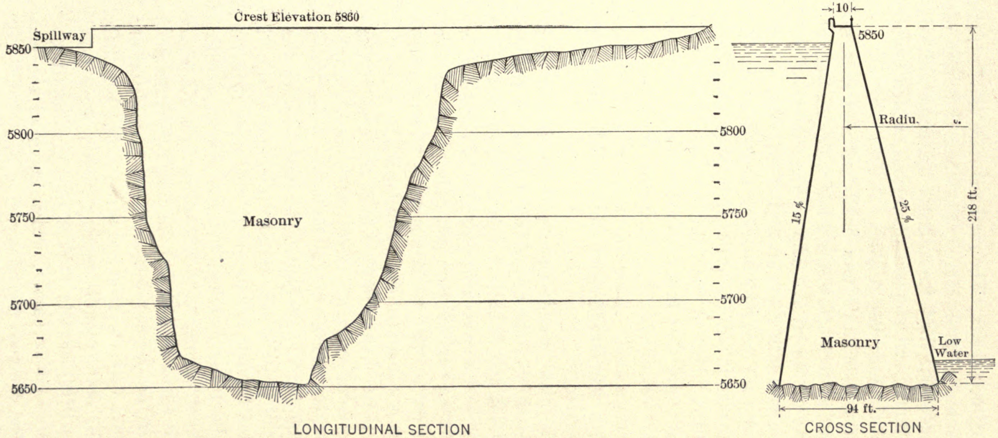


FIG. 62.—Profile and Section of Pathfinder Dam, North Platte River, Wyoming.

dams to strengthen them. The methods were efficient, and good progress was made until March 25, when the river rose suddenly and caused the thick ice to break up, flooded the dam site, wrecked the flume, and stopped operations, which could not be resumed until the following August.

An excellent foundation was finally secured at a maximum depth of about 21 feet below mean low water and about 14 feet below the bed of the river. The average depth of excavation over the entire foundation was about 10 feet. When rock bottom was first exposed a perfect foundation, already prepared, seemed assured, as the rock surface presented many irregularities and dipped toward the heel of the dam, but as the excavation progressed it was found that this admirable foundation was underlaid by a mud seam, from 1 to 4 inches thick, and contained many transverse seams. After this layer of rock was removed, sound bed-rock was encountered which, with some roughening, was very satisfactory.

Plant.—The plant was designed with the idea of economizing as much as possible in the use of labor owing to the great difficulty in obtaining and keeping laborers. With this idea in mind the machinery was placed as compactly as consistent with efficient use; hoisting engines were generally placed in pairs, under the same shelter, so that when engineers were scarce or when work was slack one engineer could run both hoists.

The main power house, located near the edge of the canyon just above the dam, contained three boilers with a total capacity of 140 horse-power. Steam was delivered from these boilers, which were coupled to a 6-inch main pipe line, to the mixing house, crusher, derrick hoists, steam drills, and to the high-pressure pump that furnished water from the river to a portion of the plant. The plant included ten guy derricks, with 60-foot masts and 55-foot booms, ten double-drum hoisting engines, two cableways with spans of 350 feet, having capacities of ten and fifteen tons each, one air compressor, three steam drills, one No. 4 gyratory crusher, with elevator and screens, one No. 2 Ransome concrete mixer, one Iroquois mortar mixer, three 6-inch centrifugal pumps with electric motors, one 35-kilowatt generator, and one 85-horse-power engine, which operated the generator, crusher, and the concrete machinery.

In order to economize cement and secure the best results the

specifications required all stone to be laid in beds of mortar and the vertical joints to be filled with concrete. It was accordingly necessary to provide two types of mixer and to handle two classes of product.

One of the most difficult and expensive problems to meet was that of fuel. Soon after the contractors commenced work on the dam they made arrangements to obtain wood from the Pedro Mountains, eight to ten miles south of the dam site. Several four-horse teams were steadily employed hauling the wood to the south side of the canyon. It was then loaded on a wood rack, holding about one and one-half cords, taken across the canyon by one of the cableways, lowered on a car and run out to the boiler house. The wood was pine and cedar, and five cords a day, costing from $8 to $10 per cord, were used when all the machinery was in operation.

The cars containing mortar or concrete were run out under the cableways and delivered by them to the derricks on the wall. When possible the concrete was dumped directly from the cableway. The mixing plant was designed for compactness, and, though small, was capable of furnishing the material as fast as practicable to use it. One man handling the cement and another man operating the mixers mixed eight hundred sacks of cement in a day of eight hours, or one hundred sacks per hour; this gave a limit of 225 cubic yards of masonry in a day.

Practically all the backing stone and stone for crusher was obtained from the spillway excavation. A system of narrow tracks facilitated the handling of the material taken from this quarry. The stone blocks were thoroughly washed with a hose and scrubbed with a broom, placed on a flat car and run under the larger cableway for delivery on the dam. Spalls and chunks from this quarry were handled in the same way except that they were loaded into iron skips or pans. The plant in this quarry consisted generally of three derricks with double drum hoisting engines and from 1 to 2 steam drills, the power coming from the central plant.

Canyon Wall Excavation.—The specifications required that "the side walls of the canyon shall be cut away until they present surfaces normal to the face of the dam, suitable, in the judgment of the engineer, for solid and safe junction with the masonry." The south canyon wall presented no difficulties in attaining satis-

factory ties. The excavation of the north canyon wall was not as satisfactory and was much more expensive. On this side the trend of the seams was at an angle of about thirty degrees from a radial line of the dam, necessitating special work to obtain a suitable bearing of the masonry on the abutment. After the masonry had been carried to the top of the north canyon wall and excavation was in progress some 20 feet back from the edge, a vertical seam that had been covered by a layer of seamy rock several feet thick was encountered, the up-stream half of which was filled with dirt, apparently surface material that had been deposited after the immense slab of rock had slipped or tipped from the main body, while the down-stream portion was filled with rock more or less fissured, some of which was removed. The seam was cleaned out for a depth of 30 feet by softening the material with water, then excavated by means of a small scraper. After thoroughly cleaning the seam it was filled with rich concrete mixed very wet. As the depth of filling per day was from 10 to 15 feet, and the material used very wet, there could be no question but that every void was filled and that this portion of the work was as strong as any other. If the presence of this seam had been known before masonry had been built against the rock forming one side of it, it would probably have been removed, but careful estimates show that to have done so would have cost at least $20,000, while the method adopted made just as good work at a cost of only a few hundred dollars.

Masonry Work.—The first stone was laid August 15, 1906, and masonry work was continued until the latter part of November, when cold weather made it necessary to discontinue this portion of the work. The top of the masonry was then at elevation 5,670, or 24 feet above the lowest point of foundation, and contained 5,500 cubic yards of masonry. Work was resumed early in March, 1907, but the work was flooded several times during March and April and, as frequent repairs to the temporary dam were necessary, progress was slow. As the work proceeded a notch was left at the south end of the dam to allow the spring floods to pass. Two lines of 36-inch cast-iron pipe were built through the dam, on a 1 per cent slope, their inverts being at elevation 5,676. The purpose of these pipes was to carry the low-water flow of the river when operations in the tunnel necessitated the closing of its upper end. Masonry work was suspended

May 22 on account of high water until July 6, when the floods subsided sufficiently to allow of work by racking up from the notch. By August 16 the river had dropped sufficiently to allow of working in this gap, but it was necessary to repair the coffer-dam, force most of the water through the tunnel, and care for the seepage by pumping. The filling of this notch consumed practically the two months of August and September, and thereafter the masonry was kept nearly level.

To provide additional waterway during the time the tunnel was closed for the installation of gates, an opening was left through the dam to assist the 36-inch pipes in keeping the reservoir at a low level. This opening is 4 × 4 feet with a semicircular top, tapering in the upper 16 feet to a width of 6 feet, 4 feet high to the springing line, and having a semicircular top with a radius of 3 feet.

Before bedding the stone on the bed-rock, the foundation was broomed over with thick cement grout, particular care being given the up-stream portion; this was also done on the canyon walls for the 5 feet nearest the up-stream face. The method of placing the material was as follows: When the dam was levelled up, a course was laid on each face, 2 to 1 mortar being used on the upper and 2½ to 1 on the lower face. Backing stone, varying in size from 1 to 5 cubic yards, were then set as thickly as possible between the face courses, and where there was not room for a fair-sized stone a spall was often placed. These stones were always set in a heavy bed of 2½ to 1 mortar and the vertical joints filled with concrete, mixed in the proportion of 1:2½:4, except the upper 30 feet of the dam, in which a mixture of 1:3:4.8 was used. Until March 1, 1909, the cement used was .903 barrels per cubic yard, the following table showing the proportions of all the materials entering into the construction of the dam at that time:

	Per Cent
2 :1 mortar	1.3
2½:1 mortar	11.3
1 :2½–4 concrete	38.6
Stone (including spalls)	48.8

Soon after March 1, when the dam was within 30 feet of the top, the remainder of the dam being a gravity section, the con-

crete mixture was changed by using two and one-half instead of three sacks of cement to a batch, which gave the proportion 1:3:4.8.

The total quantity of cement used in the construction of the dam and auxiliary works was 57,383 barrels.

The specifications called for 2-inch joints for the face stone, and the stones were cut to meet this requirement, but the joints will not average over 1½ inches.

During the early part of the work, stones 2 feet thick were used, as the contractors thought stones of that size were the most easily handled, but when quarry No. 2 was opened it was found that 3-foot patterns could be obtained more economically and the bulk of the stone cut after the second season was three feet thick. No stretchers were less than 3 feet long or 2 feet deep. About one-fourth of the area was composed of headers, which, according to the specifications should be 6 feet long, but as it was difficult to obtain that length, many were used that were only four feet long. The face stones were set in the same manner as backing stone, on a stiff bed of mortar and shaken down until all surplus mortar floated out. The pointing of the upper face was very carefully done; joints were raked out for a depth of 2 inches soon after setting the stone, and, while being pointed, were thoroughly scraped, washed out, and packed with 1 to 1 mortar.

The top of the dam has a parapet wall 4 feet high and 2 feet wide on the up-stream side and a gas-pipe railing 3½ feet high on the lower face, leaving a roadway which was given a granolithic finish.

On account of the great extremes of temperature to which the masonry would be subjected, the question of thermal stresses was carefully considered. The canyon being so narrow below elevation 5,830, it was assumed that in that portion the arch shape and numerous joints would take up the expansion and contraction, especially as during the warmest weather the reservoir would be filled to this elevation, which would protect the up-stream face while the lower face would only be exposed to the sun a few hours in the forenoon and consequently not subject to extreme change. But above elevation 5,830, about 30 feet below the top, reinforcement was used near the faces of the dam, a flat deformed bar being placed in the mortar joints. The gen-

Fig. 63.—Pathfinder Dam, looking upstream, North Platte River, Wyoming.

eral plan was to place three 2 × ½-inch slant rib bars in the mortar when setting the face stone, the outer bar being from 9 inches to 1 foot from the face of the stone and the others 1 foot apart; immediately behind the face stone a 1½-inch twisted bar was bedded in the concrete; in the upper 5 feet additional bars were placed. This gave an area of about 4½ square inches of steel in each 3-foot course, and amounts to nearly .25 of 1 per cent for the outer 5 feet of the dam. The ends of the rods were not turned but were lapped from one to 1½ feet on the next rod. About 100,000 pounds of steel were used in the reinforcement.

Expansion joints were constructed at the ends of the main dam. This joint is merely a groove and tongue to prevent excessive leakage, though it is not expected that much leakage will occur at these points, as the masonry will be in expansion when the reservoir is filled to this height. The surface of the joint first finished was thoroughly oiled before the next was built against it. Since filling the reservoir, the dam shows some sweating, but no leakage.

The final estimate given the contractors for the construction of the dam, including the spillway dam, gate-house foundation, and guide wall, but not including cost of cement or reinforcing steel, was as follows:

Work		Quantity	Unit Price	Amount
Masonry	Above 5,660......	57,278 cu. yds.	$6.25	$357,987.50
	Below 5,660......	2,937 " "	9.00	26,433.00
Excavation	Class 1..........	1,959 " "	2.00	3,918.00
	Class 2..........	1,828 " "	6.00	10,968.00
	Class 3..........	9,486 " "	4.00	37,944.00
	Concrete...........	541 " "	6.50	3,516.50
Hauling cement from Casper to dam site.....................		56,641 barrels	3.00	169,923.00
Extra work....................		....	....	15,240.27
Total.............		....	....	$625,930.27

Spillway.—At the north end of the dam (Fig. 7) a natural ridge of rock, nearly level, at about elevation 5,850, extended back from the canyon for a distance of 400 feet and terminated in a rocky hill from 10 to 40 feet higher. Advantage was taken of these natural conditions. It was decided to excavate the

rock at the north end of this ridge to elevation 5,850 and use the material in the construction of the dam, thus obtaining an adequate wasteway at practically no expense, and providing 80 per cent of the stone used. The finished spillway has an effective length of 650 feet and is capable of passing at a depth of 8 feet over 45,000 cubic feet of water per second.

A concrete guide wall (Fig. 7) was constructed along the canyon side of the spillway, to prevent the water from falling near the toe of the dam; it will confine the overflow to a natural rock channel having a 10 per cent slope.

Anticipating the installation of gates in the outlet tunnel, and the necessity for closing the upper end of the tunnel while that work was being done, a concrete seat for a timber bulkhead was built at the tunnel entrance before the river was turned into it. The span being 13 feet and the head of water expected about 75 feet, slots were left at top and bottom of the opening for two 24-inch I-beams to act as a middle support to the bulkhead. The tunnel was driven with a width of 16 feet at the intersection with the shafts, but the design of the gates called for a chamber 28 feet wide by 35 feet long by 10 feet high, except at the shaft where it was 50 feet high. Before commencing this excavation, it was necessary to close the upper end of the tunnel. The I-beams were placed in position with the help of guy lines fastened to the lower end; the wooden bulkhead was built above water, the upper end secured in place by a hinge, and the other end lowered into the water, where it was quickly and tightly closed by water pressure. The installation of the gates presented no special difficulties. On account of the great weight of some of the castings, 12,800 pounds being the maximum, and the limited space for handling them, progress was slow. The total weight of the castings and kindred material placed was 450,000 pounds. The preparation of the chamber for their reception involved the excavation of 525 cubic yards of rock and the placing of 660 cubic yards of concrete.

Grizzly.—After the gates were installed a grizzly was constructed at the tunnel entrance to prevent drift from entering and possibly lodging in the gate openings. While this was a small piece of work, it proved to be one of the most difficult undertaken, owing to its location. It was impossible to get a team near the work and transportation by boat was out of the

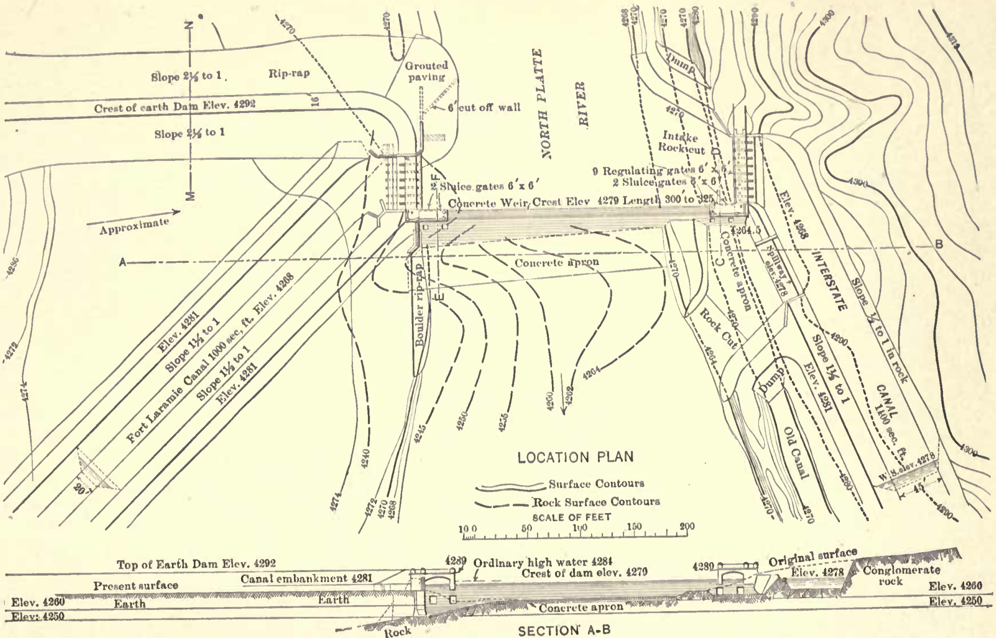


Fig. 64.—Plan and Elevation of Whalen Diversion Dam, North Platte River, Wyoming.

question on account of the rapids at the upper end of the canyon. After a careful study of the situation, a timber chute was built from the top of the canyon to the river bank below. This chute was 185 feet high, at an angle of 66° with the horizontal, suspended mainly from the top and braced every 15 to 20 feet from the canyon wall. A tripod with pulley was erected over the upper end of the chute and a hand winch set up 100 feet from the edge of the canyon. All the material used was lowered down the chute.

PATHFINDER DIKE

A few hundred feet south of the Pathfinder Dam, occurs a low saddle in the margin of the reservoir about 30 feet below the level of the spillway, and in this gap has been built an earthen dike, 1,600 feet long and 40 feet in maximum height. It has a core wall of reinforced concrete, and its water slope is paved with rock to resist wave action.

The portion of this dike on the water side of the core wall is composed of a sandy clay loam, hauled in dump wagons which were loaded by elevating graders, and after dumping on the dam, the earth was spread by means of road scrapers into 6-inch layers, and rolled with a traction engine. This engine was employed one shift per day in drawing the elevating grader, and on the other shifts was used for rolling not only the half of the dam that it helped to build, but the lower half also. The latter was composed of gravel excavated from a bank southwest of the dike, and hauled in dump wagons. This structure was built in 1910 by Government forces.

WHALEN DIVERSION DAM

The water for the North Platte Project is diverted near Whalen, by a concrete, overflow, ogee weir, founded on rock, designed as shown in Fig. 64. Provision is made for taking water from both ends of the dam, and two sluice-gates are provided at each end for clearing the entrance to the canals. The headgates of the Interstate Canal are placed at right angles to the dam, and are of cast iron, nine in number, working in a structure of concrete. They are shown in Figs. 65 and 66.

Dam No. 1.—The dam which forms the first reservoir in the valley, or Lake Alice, is an earthen structure about 28 feet in

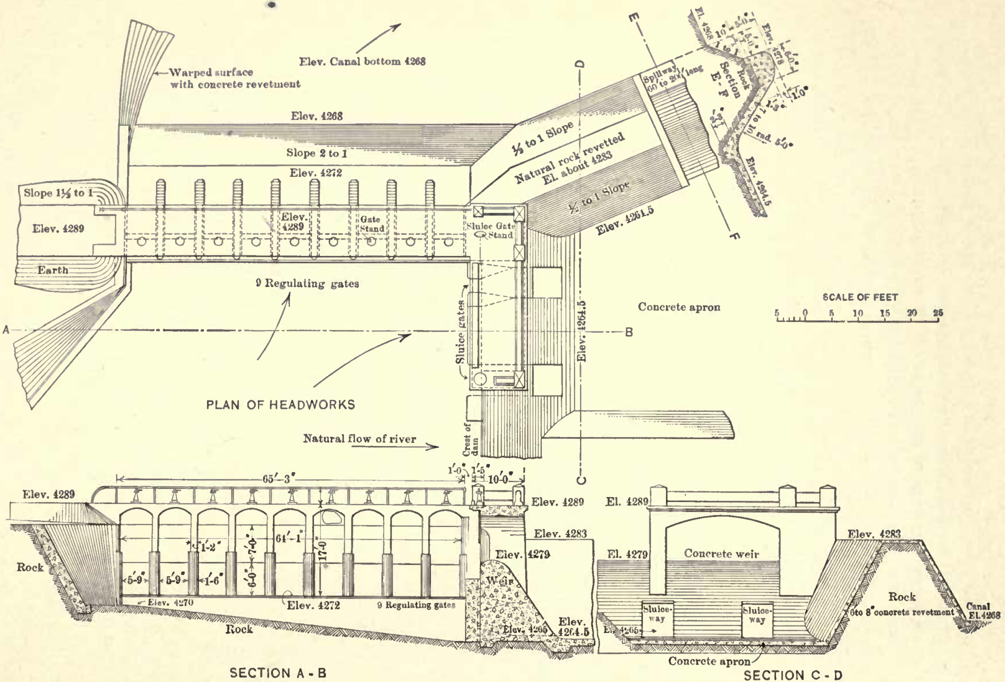


FIG. 65.—Plan and Elevation of Head-works, Interstate Canal, North Platte River, Wyoming.

maximum height, and 3,200 feet long. It has a top width of 20 feet, the water slope is 3 to 1, and the down-stream slope $2\frac{1}{2}$ to 1. The water slope is riprapped with rough rock pitching $2\frac{1}{2}$ feet thick to protect the slope from wave action. The down-stream slope to the extent of $\frac{1}{6}$ of the embankment is of Brulé clay and the remainder of the dam is a sandy loam, which was wetted and rolled in layers of about 8 inches. At the junction of the two classes of material, a subsurface drain of clay tile is placed parallel to the axis of the dam with an outlet to the lower toe. The drain is 8-inch drain tile laid in a trench 5 feet below the ground surface, and covered with screened gravel. At intervals of 50 feet along this trench, wells of 19-inch diameter were sunk to Brulé clay or gravel.

A cut-off trench, from 20 to 30 feet deep with a bottom width of 6 feet and side slopes of 1 to 1, was carried down into the Brulé clay 3 to 5 feet, and filled with puddled material. It is located about the upper edge of the middle third of the dam.

After this dam was completed and water raised upon it, seepage began to appear in the borrow pits below the dam and on the surface of the ground in the vicinity, but there were no indications of a concentrated flow, nor of any leakage whatever through the dam itself. The leakage appears to pass under the puddle trench through crevices in the Brulé clay. Drains were provided for the wet ground below the dam, and the seepage seems to be decreasing.

The outlet consists of a reinforced concrete culvert containing three conduits 4 feet high and 3 feet wide. The culvert has cut-off walls at each end, and also has three collars 3 feet deep and 15 inches thick, to cut off percolation. There are three gates of cast iron controlled by hand power, and a groove for flash-boards to permit shutting off the water in case repairs to the gates become necessary.

MINITARE DAM

The Minitare Dam is an earthen embankment with a down-stream toe of gravel. Its maximum height is about 55 feet above the valley, and its length is about 3,800 feet. A short distance above the center line it has a cut-off trench and a core-wall of reinforced concrete reaching to depths below the surface, varying

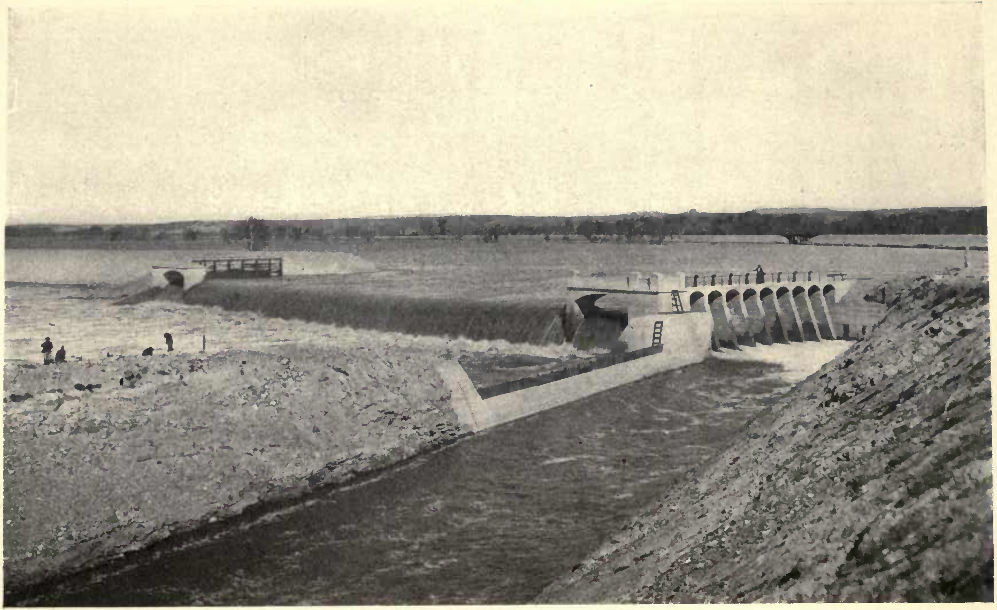


Fig. 66.—Whalen Dam and Head-works Interstate Canal, Nebraska.

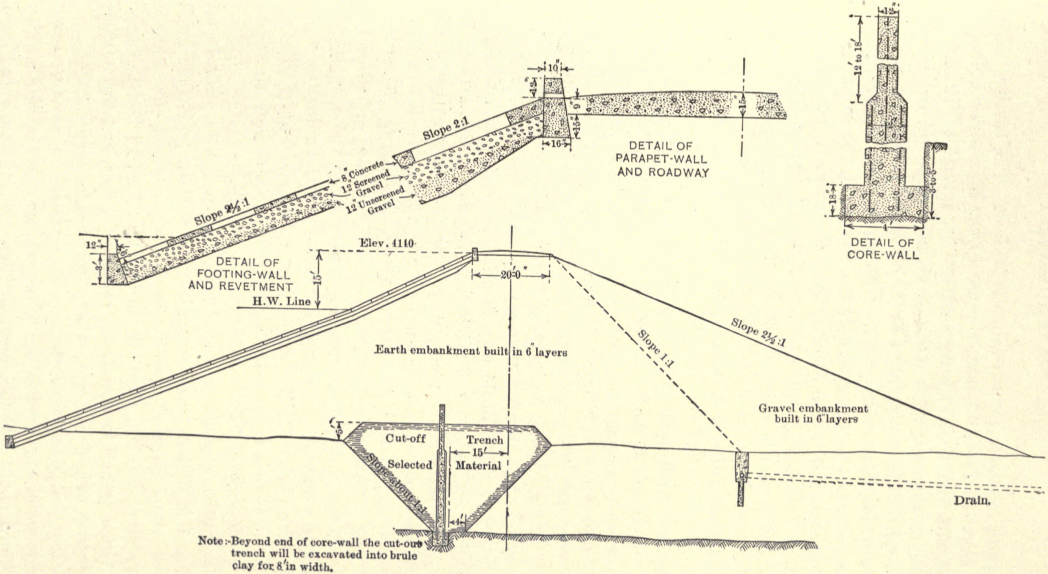


FIG. 67.—Typical Section of Minitare Dam.

from 10 to 52 feet. Its top width is 20 feet. The earthen bank has a slope of 2½ to 1 from the toe to the high-water line and a slope of 2 to 1 above the high-water line, a vertical distance of 15 feet, to the top. The earth is given a slope on the downstream side of approximately 1 to 1, and gravel is added sufficient to flatten this slope to 2½ to 1. The water slope is paved with concrete blocks extending 16 feet up and down the slope and 8 feet longitudinally of the dam. Under the concrete pavement is a foot of screened gravel, and under this a foot of unscreened gravel lying on the earthen slope. The right abutment slope and the central portion of the dam are founded on a sandy loam soil underlaid with Brulé clay at depths varying from 10 to 20 feet.

The left abutment hill is composed mainly of gravel, with some admixture of sand. It was the original intention to carry the core-wall through the loam soil and 4 to 5 feet into the Brulé clay, but it was found on opening up the trench that the Brulé clay was traversed in all directions with numerous open cracks through which water might flow with considerable freedom, and it was decided to carry the wall below these cracks to solid clay. The Brulé clay is an indurated clay containing some grit, and where not fissured is practically impervious to water. To reach solid material, it was necessary to carry the wall in some places to a depth of over 60 feet below the surface, and even so, the foundation developed some leakage when put in service. Beneath the junction of the earth and gravel of the embankment, a tile drain was laid, parallel to the axis of the dam, with a discharge drain at the bottom of the valley to carry the drainage below the toe of the dam. A channel lined with reinforced concrete is provided around the west end of the dam, with a capacity of 1,500 cubic feet per second.

The outlet conduit is placed in a trench cut in solid Brulé clay, and is of reinforced concrete with bottom and sides built against the indurated clay in place, and provided with cut-off collars every 25 feet, about 30 inches deep and 18 inches thick. The top is arched to an interior radius of 4 feet, and the bottom invert to a radius of 8 feet, with straight sides about 3 feet.

After the Minitare Reservoir was placed in service, some seepage water appeared in the country below, and several springs developed about 400 feet from the dam, which aggregated from

2 to 3 cubic feet per second. The total seepage from the reservoir was not excessive and decreased with time, as it normally should, but the concentration of a portion in large springs so near the dam was undesirable and means were adopted for diminishing the specific leakage referred to on the theory that the water had found open seams in the Brulé clay passing under the core-wall near the center of the dam, where, owing to a rise in the surface of the Brulé clay, the core-wall had not been carried as deep as at other places, and, moreover, was only from 16 to 22 feet in the clay as against 30 to 40 feet at other points.

To fill the crevices in the clay at this place, a number of holes were drilled down through the dam just above the core-wall at intervals of 10 feet, and were treated with a grout of fine sand and cement pumped into them under pressure. These measures were successful in practically stopping the leakage.

Final Estimates of Contract for Construction of Minitare Dam

Item	Quantity	Unit Price	Amount
1 Preparing surface	17,724 acres	$200.00	$3,544.80
2 Cut-off trench, Cl. A	104,162 cu. yds.	.35	36,456.70
2A Cut-off trench, Cl. A excess of 10′ depth	442,397 " " ft.	.02	8,847.94
3 Cut-off trench, Cl. B	9,362 " "	1.00	9,362.00
3A Cut-off trench, Cl. B excess of 10′ depth	137,376 " " ft.	.03	4,121.28
4 Excav. drain & toe trench Cl. A	6,563 " "	.60	3,937.80
4A Excav. drain & toe trench Cl. A in excess of 8′ depth	690 " " ft.	.02	13.80
5 Drain trench, Cl. B	135 " "	1.00	135.00
5A Drain trench, Cl. B in excess of 8′ depth	870 " " ft.	.03	26.10
6 Laying drain tile	4,004 lin. ft.	1.00	4,004.00
7 Outlet channel, Cl. I	39,853 cu. yds.	.32	12,752.96
8 Outlet channel, Cl. II	7,635 " "	.60	4,581.00
10 Outlet conduit, Brulé	5,277 " "	1.00	5,277.00
11 Excav. spillway, Cl. I	46,513 " "	.25	11,628.25
12 Excav. spillway, Cl. II	2,837 " "	.50	1,418.50
15 Earth excav. for embankment	522,833 " "	.30	156,849.90
16 Gravel excav. for embankment	140,814 " "	.30	42,244.20
17 Trimming embankment	6,354 " "	.30	1,906.20
18 Gravel for roadway and upstream slope of embankment	15,176 " "	.45	6,829.20
21 Wells	572 lin. ft.	.75	429.00
22 Concrete Masonry, Cl. A	9,474 cu. yds.	4.60	43,580.40
23 Concrete Masonry, Cl. B	1,684 " "	6.00	10,104.00
24 Concrete Masonry, Cl. C	506 " "	6.00	3,036.00
25 Concrete Masonry, Cl. D	5,622 " "	5.00	28,110.00
26 Handling and Placing Steel	459,000 lbs.	.01	4,590.00
	Total		$403,786.03

Summary of Cost
December 31, 1914
Nebraska, Wyoming, North Platte Project

Feature	Cost	Contract, Per Cent	Government Force, Per Cent
Storage Works:			
Pathfinder Reservoir	$1,795,524.37	69	31
Lake Alice Reservoir	209,730.19	38	62
Lake Minitare Reservoir	464,630.80	100	..
Diversion Works:			
Whalen Diversion Dam	235,010.54	62	38
Main Canal System:			
First Division Interstate	1,028,041.87	88	12
Second Division Interstate	849,340.29	98	02
High line canal	142,898.08	53	47
Reservoir supply canal	42,322.07	62	38
Low line canal	226,557.29	59	41
Distribution System:			
Rawhide lateral district	3,819.31	..	100
First lateral district	359,652.94	46	54
Second lateral district	285,034.79	57	43
High line lateral district	80,793.45	37	63
Reservoir supply lateral district	75,768.45	43	57
Low line laterals	95,007.69	45	55
Drainage System:			
Open and closed drains	98,326.82	..	100
Real Estate	26,796.34	..	100
Buildings	30,466.13	16	84
Farm Unit Subdivisions	43,511.61	..	100
Miscellaneous Preliminary Investigations and Survey	81,114.55	..	..

SALE OF STORAGE RIGHTS

Before the inauguration of the Government Project on the North Platte River, the waters of that river were appropriated by ten canals in Wyoming to such an extent that in low-water years the river was practically dry at the State line in the late summer, and all the canals in Nebraska were then short of water. There are more than forty canals in Nebraska diverting water from the North Platte, and most of these are short of water in the last half of the irrigation season in all ordinary years, and the completion of their supply is one of the functions of the Pathfinder Reservoir, which stores the winter flow and surplus floods of spring and releases them when needed in the summer and fall. All the more important canals in Nebraska have purchased reservoir rights, and thus completed their irrigation supply.

The terms of the contract are so drawn as to eliminate as far as possible the chances of future dispute and litigation. When a district applies for water, it is asked to decide upon a curve of delivery from day to day during the season which will satisfy its needs. This demand curve is then compared with the dis-

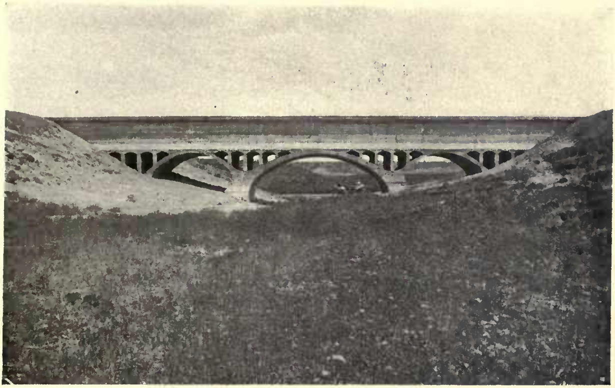


FIG. 68.—Spring Canyon Flume, Interstate Canal.

charge curve of the river, and the demands of other canals which are prior in right to the district mentioned, and from this information a conclusion is reached as to how many acre-feet of water are required to complete the delivery curve requested. The district agrees to pay for that number of acre-feet, and the United States agrees to furnish at the State line the quantity of water required to fulfil the delivery curve each day in the season forever, regardless of the season. It thus becomes unnecessary to distinguish between the natural flow of the river and the water drawn from storage. This eliminates a very difficult and irritating problem and enables the United States to utilize all available supplies, including drainage and storm waters, and, if carried out fully, will place the administration of the waters of the North Platte under one management. The elimination of litigation in this and many other Western valleys is by no means the least of the benefits conferred by the Reclamation Act.

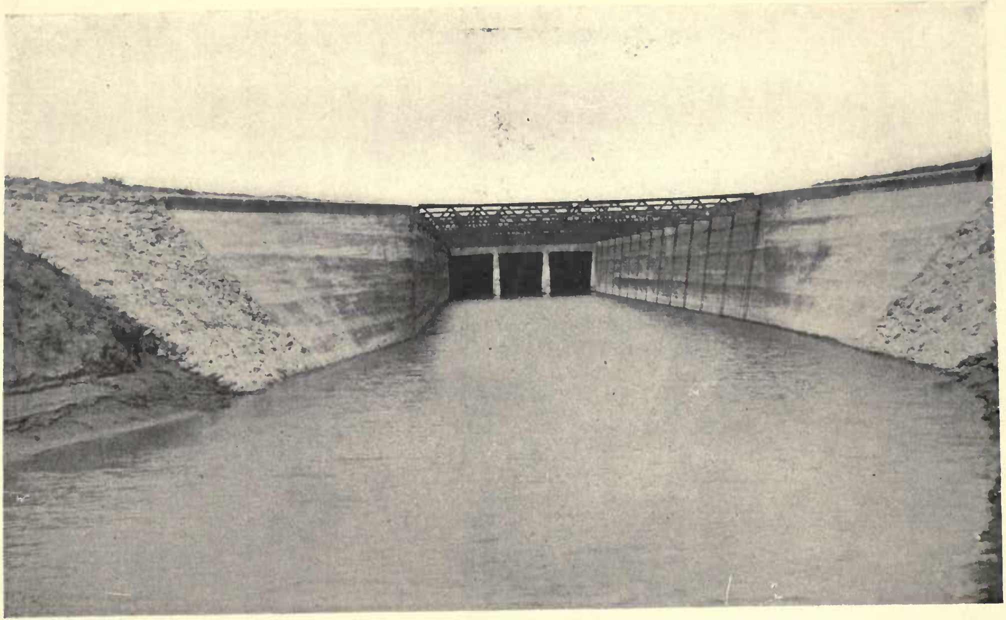


FIG. 69.—Entrance to Rawhide Pressure Conduit, Interstate Canal, North Platte Project, Nebraska.

AGRICULTURAL RESULTS

The North Platte Project has an average altitude of 4,100 feet above sea-level, and its soil varies from sand to sandy loam. It is rather rolling, being in places quite rough and difficult to irrigate. This is indicated by the fact that 6,445 canal structures are provided for the irrigation of 129,684 acres of land on 806 miles of canals.

Seepage from the canals and excessive irrigation have caused the rise of ground water in some localities, but this has been largely remedied by drainage, thirteen miles of open and nine miles of closed drains having been constructed.

Notwithstanding the difficulties, the development of agriculture has been good and fairly steady. This development has been as follows:

	1910	1911	1912	1913	1914	1915
Area for which service was prepared to supply water..	87,994	96,898	103,837	109,272	109,341	129,584
Area irrigated....	48,537	49,411	55,631	63,366	67,700	73,881
Miles of canals operated..........	487	534	602	648	652	806
Number of farms irrigated........	.....	.....	777	908	944	1,050

The delivery of water on the North Platte Project has thus far been on a continuous flow plan almost entirely, the rotation method not having been introduced to any considerable extent.

FORT LARAMIE UNIT

Construction has recently been started on a canal heading at the Whalen Dam on the south side of the river. This canal will have about twenty-five miles of heavy construction, including three tunnels aggregating 8,550 feet in length. It will cross the Goshen Park and irrigate about 55,000 acres in Wyoming, mostly State and public land, and about 45,000 acres in Nebraska, mostly private land. It can later be extended to cover more land in Nebraska should the water supply prove sufficient.

The Pathfinder Dam was built by E. H. Baldwin, and the Interstate Canal by John E. Field, under general direction of

FIG. 70.—Flight of Drops; Baffle Pasts in Foreground. North Platte Project.

C. E. Wells, Supervising Engineer. The major part of the distribution system and the Minitare Dam were built by Andrew Weiss, under direction of R. F. Walter, as Supervising Engineer.

The Fort Laramie Canal is under the immediate charge of O. T. Reedy.

CHAPTER XII

TRUCKEE-CARSON PROJECT

DESCRIPTION

The irrigable lands and most of the works of the Truckee-Carson Project lie in western Nevada in the basins of the Truckee and Carson Rivers, which furnish the principal water supply. The natural drainage of the Truckee River is into Pyramid and Winnemucca Lakes, and the two outlets of the Carson naturally empty into Carson Lake and Carson Sink. None of these lakes have any outlet to the ocean, but dispose of their waters entirely by evaporation.

The water supply available from the Truckee is larger than that from the Carson, but the latter has a much greater area of valley land available for irrigation, so it becomes desirable to take water from the Truckee into the Carson basin.

Although these basins are quite distinct, there is a low pass between them, just east of Wadsworth, through which it is feasible to carry the water in a canal.

On the headwaters of the Truckee River are a number of small lakes and other small reservoir sites, and one very large one, Lake Tahoe, which are available for storing the flood waters of their respective drainage areas which, however, aggregate less than half the mountain drainage area of the Truckee River.

The Carson River basin is not so well supplied with storage facilities on its headwaters, but has a good reservoir site on its lower trunk at Lahontan.

There is considerable irrigation by private enterprise on the Upper Truckee in the neighborhood of Reno, Nevada, and the water is all appropriated for this purpose in the latter part of the season in ordinary years. Lake Tahoe is, accordingly, being utilized as a storage reservoir.

A large number of small canals have been built in the valleys of the Upper Carson, and several in the lower valleys. Many of these canals were dry in the late summer in years of ordinary

or short supply before the advent of the Reclamation Service, and nearly all were short in low-water years.

Large irrigation development in the Carson Valley depended therefore upon the storage of such flood waters of the Carson as remained unappropriated, and upon bringing available waters from the Truckee Basin, which also consisted mainly of unregulated floods and the winter flow.

A diversion dam has been built on Truckee River near Derby, Nevada, and a canal of 1,200 second-feet capacity at the head carries the water to the bench lands east of Wadsworth and to the reservoir that has been provided near Lahontan on the Carson River.

The waters released from the Lahontan Reservoir are diverted from the Carson River by a concrete diversion dam about five miles below the reservoir into a canal of 1,800 second-feet capacity on the right bank and one of 300 second-feet capacity on the left bank.

LAKE TAHOE STORAGE WORKS

Lake Tahoe has an elevation above sea level of 6,225 feet and an area of about 193 square miles, about one-third in Nevada and two-thirds in California.

About 326 square miles of high Sierra Mountain slopes drain into the lake. The outlet is at the northwest extremity on the California side, where the main Truckee River begins. The river runs first in a northerly and then a northeasterly direction and crosses the State line into Nevada near Floriston. In this vicinity are a number of power plants which use the waters of the Truckee River for the development of water power.

In order to regulate the outflow from the lake, a low crib dam was constructed across its outlet many years ago, and this was used to control the flow for the flotation of logs and later for the use of the power plants near Floriston. These works were temporary in nature and inadequate in capacity to fully utilize the storage capacity of the lake, and the United States has acquired the outlet and constructed a concrete dam provided with gates of large capacity so that the level of the lake can be closely regulated at will.

The structure consists of a series of seventeen gates separated by piers 18 inches thick, each gate having 5 feet clear span, and

a height of 4 feet from the sill to a curtain wall extending upward 10 feet to the level of extreme high water. The piers extend 18 feet up- and down-stream, and the river-bed between is paved with concrete. The river-bed for a distance of 15 feet downstream from the structure is paved with grouted riprap, and the sides are finished to a $1\frac{1}{2}$ to 1 slope and protected with grouted paving.

The power plants on Truckee River, of course, require water the year round, and as fall and winter constitute the low-water season, the draft on the storage in Lake Tahoe is greatest at that time, and would be entirely lost to irrigation unless stored elsewhere. To save this water and also to store the flood waters of the Truckee and Carson Rivers, the storage reservoir has been constructed on the lower Carson River, at Lahontan, receiving its most reliable water supply through a canal from the Truckee.

TRUCKEE MAIN CANAL

The main canal from the Truckee to the Carson River heads about ten miles above Wadsworth, and is employed for the irrigation of lands near Fernley and to carry water to the Lahontan Reservoir, which depends mainly upon this source for its water supply.

The river at the diversion point crowds the mountainside on its right bank, and leaves a small, gradually sloping valley on the left. The diversion is made by a long, earthen dike across the valley and a concrete structure in the river-bed, consisting of a series of sixteen gates of 5-foot horizontal opening, with 5-foot piers between, making the distance between abutments 155 feet.

The vertical openings are 15 feet high, 10 feet of which are closed by the gates, and above these flash-boards are used. Each gate is in two leaves, one above the other, which it slightly overlaps. The hand-operated gate stem engages the lower leaf only, so that in starting only half the friction and half the weight have to be overcome. When the lower leaf has risen $4\frac{3}{4}$ feet, a lug engages the upper leaf, which is then moved usually without water pressure.

The head-gates of the canal are eight in number, and placed at right angles to those in the river, the two sets of gates and

FIG. 71.—Head-works, Main Truckee Canal, Nevada.

their foundations forming one structure and using one abutment in common.

The concrete foundation is 8.8 feet thick and 30 feet wide up and down stream, resting on a natural bed of gravel and boulders. It is about 171 feet long, or about 25 feet greater than the width of the river-bed. About two feet down-stream from the upper edge of the foundation, a row of interlocking steel piling was driven into the gravel a depth of about 8 to 10 feet. The piles are built up of channels of 3/8-inch steel 15 inches wide, weighing 33 pounds per linear foot. The pile cut-off extends a short distance beyond the foundation on each side. The piles extend upward into the concrete from two to four feet, the total length of each pile being 12 feet. For a distance of 30 feet down-stream from the foundation the river-bed was paved with large rock.

After this dam was placed in operation, a great flood occurred in 1906, far beyond previous records, carrying a large amount of drift. As a result of this experience, it was thought advisable to remove the top of one pier in order to provide automatic passage for drift. A pier near the left abutment was removed down to an elevation 2 feet lower than the level of water in the canal running full, and the top sections of the two adjacent gates were also removed. A wooden sill 10″ × 12″ was placed on top of the adjacent piers spanning the opening, and to support the tops of needles employed to close the opening at low water. By removing this sill and the needles, a clear opening 15 feet wide and 21 feet high is obtained, and this opening is 17½ feet in the upper 6 feet. This seems to be sufficient passage for drift.

In the head-works of the canal are nine gates, each having a clear span of 5 feet, with piers 2 feet wide between, which are built-up steel girders encased with concrete. These are surmounted by a deck 64 feet long, which is also a girder, imbedded in concrete, and serves not only as a deck to carry the gate stands, but acts as a beam to take one-third the horizontal thrust of the high water. The sill of each gate is 2.7 feet above the bed of the canal and 3.7 feet above the sills of the sluice-gates of the dam, in order to facilitate sluicing of gravel and sand through the dam.

On the river side of the head-gate structure is a curtain wall carried 3 feet below the foundation to prevent the entry of water

beneath the gates. The canal just below the head-gates has a bottom width of 55 feet, with vertical sides of concrete, and gradually changes by warped surface to a bottom width of 20 feet, with side slopes of 1½ to 1. Just below the headworks, on the river side of the canal, is a spillway lip 100 feet long at the

FIG. 72.—Waste-gates, Main Truckee Canal.

elevation of water level in full canal. The canal for over 10 miles is in a canyon with steep side-hill construction, largely in rock, so that for economy of construction the section is narrow and deep, the water depth for full canal being 12 feet. There are three tunnels lined with concrete and a large part of the canal is also lined with concrete. The slope of the canal is generally 1 in 5,000, and this is increased to 1 in 2,400 in hard-rock sections and to 1 in 1,500 in tunnels. The three tunnels are respectively 901, 309, and 1,515 feet long, the tunneling beginning when the cut reaches about 40 feet as a rule. The tunnels are 12 feet wide and have a water depth of 13 feet. The bottom is rectangular, the sides vertical, and the top arched to a radius

of 4.35 feet, springing 11 feet from the bottom. They have a theoretical velocity of 8 feet per second.

At a point in the canyon 4.6 miles below the heading, a waste-way is provided by which to empty the canal quickly in case of a threatened break or any other emergency requiring such action. A basin is formed by lowering the canal bottom six feet and widening it on the outer side to 36 feet, this basin being 45 feet in length.

The lower side of the canal is formed by a concrete wall, in the bottom of which are five gate openings each 5 × 5 feet, regulated by radial gates, counterweighted and arranged to be quickly opened. The basin serves as a trap to stop sand and silt traveling down the canal, and is quickly flushed out by opening the gates, which, under full head, have a capacity of 2,400 second-feet.

Six miles from the head of the Truckee Canal a turnout is provided to let out 200 second-feet for use on the Pyramid Lake Indian Reservation north of the Truckee River, which will be crossed here by means of a pressure pipe. In addition to the head-gates of the Pyramid Lake Canal, the same structure contains a set of six check gates across the main canal. All these gates are similar to those at the head of the canal.

The canal capacity below the Pyramid Lake turnout is reduced to 1,000 cubic feet per second, which continues with occasional slight reductions to the end at Lahontan Reservoir, which it reaches with a nominal capacity of about 800 cubic feet per second. On the way the canal serves about 12,000 acres of land in the vicinity of Fernley.

LAHONTAN RESERVOIR

The drainage area of the Carson Basin above Empire is about 988 square miles, of which the greater portion is the eastern slope and foothills of the Sierra Nevada Mountain Range. The area at Lahontan is somewhat greater, but the increment of reliable water supply between these points is small owing to the desert character of the additional area, and is more than offset in the low-water season by losses from the river-bed. The river is more often dry at Lahonton than at Empire. The reservoir when filled covers an area of 12,000 acres and has a capacity of 290,000 acre-feet. The storable run-off often falls below 100,000

acre-feet in a year, and the reservoir has in such years to depend mainly on the Truckee River through the Truckee main canal for its water supply.

Lahontan Dam.—This is one of the most unique and inter-

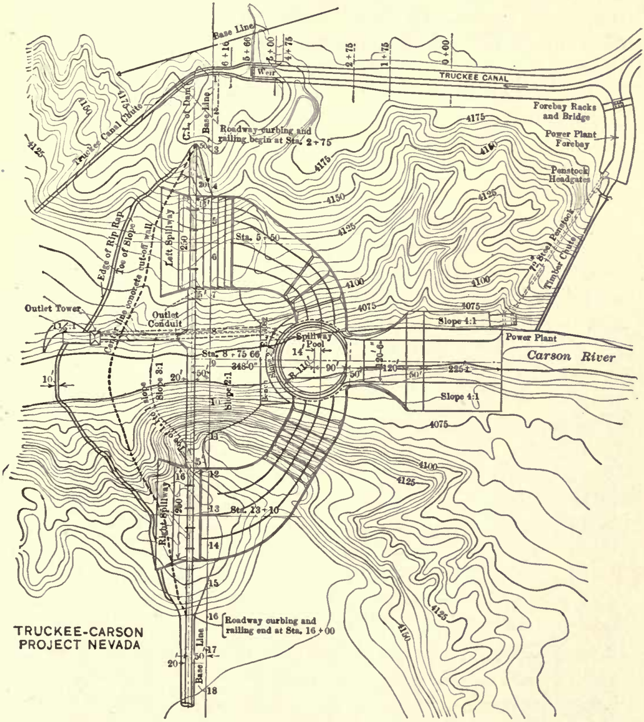


FIG. 73.—Plan of Lahontan Dam, Carson River, Nevada.

esting structures built by the Reclamation Service. It is an earthen dam built in a river with a recorded flood of 20,000 cubic feet per second, and a possible flood of twice that amount. The dam site is at a point where the Carson River cuts through a

gorge about 8 miles south of Hazen, Nevada. The right bank rises abruptly about 125 feet, as a bluff of broken and seamy rock, inclined in all directions and badly faulted. The left bank rises rather abruptly for 50 feet, where a gently sloping bench occurs, 350 feet wide, above which another steep rise of 75 feet occurs. Both sides slope gently from the bluffs to the foothills, which are about a mile from the river on the north and 2 miles on the south.

The borings showed the foundation to be similar to the abutments and revealed movement of underground waters and some artesian flow.

The surface soil of the mesas is an extremely fine silt composed of 70 per cent fine sand and 30 per cent of clayey material, to a depth of 3 or 4 feet, under which is a layer of sandy gravel from 8 to 15 feet thick, and below this a clay or sandy clay.

Percolation tests were conducted with silt and gravel mixed in different proportions to determine that most suitable to serve as a facing for the dam.

RATES OF PERCOLATION IN GALLONS PER ACRE PER DAY THROUGH 3 FEET OF MATERIAL WITH 3-FOOT LOSS OF HEAD

Per Cent Gravel	Per Cent Silt	Specific Gravity	Per Cent Voids	Percolation
85	15	2.02	17.2	162,000
50	50	2.05	18.0	20,000
0	100	1.72	23.8	14,000

The experiments showed that the rate of percolation was uniformly low with percentages of gravel of 60 per cent or less, but that percolation increased rapidly above that point. Also that of mixtures showing a low rate of percolation, a half-and-half silt and gravel gave the smallest percentage of voids and maximum specific gravity. That ratio was therefore adopted in general, but occasionally varied to suit varying character or coarseness of material.

Grouting.—In order to seal crevices and cut off percolation under the dam, an extensive system of grouting was undertaken. A cut-off trench was excavated along a line roughly midway between the up-stream toe of the embankment and the axis of the dam. This trench averaged about 30 feet in depth. A con-

crete cut-off wall was built in this trench, the latter being so excavated that one side and usually both sides could be used as concrete form and the concrete built directly against it.

In the concrete cut-off wall light galvanized pipes were built, standing in two rows, 3 feet on centers in each row, and staggered so that one pipe occurred every 18 inches. These pipes were 5 inches in diameter and were used after the concrete wall was built for drilling and grouting into the foundation below the cut-off wall. The casings were made to project above the concrete some distance, so that it was possible to carry on grouting operations with water running over the concrete. The drilling was done with a core drill of $2\frac{3}{8}$-inch outside diameter, making a core $1\frac{1}{2}$ inches in diameter. The steel calyx bit was used in the clay and very soft rock, and chilled shot equipment for the harder rock. Drilling was carried on in three daily shifts of eight hours each, and grouting in one daylight shift. The maximum depth drilled in eight hours was 19 feet, while the average was six. The seamy broken ground caused much caving and sticking of drills, and several bits and a great deal of time were lost from this cause. The holes were drilled from 25 to 70 feet below the bottom of the 30-foot excavation. Each hole was tested by piping into it water from the Truckee Canal with 127-foot head above the river-bed. The pressure was continued for about 10 minutes and the rate of leakage was usually uniform for each hole, but varied widely for different holes. The grout used was about one part cement to seven parts water except when it escaped too freely, when it was thickened until in extreme cases it was about equal parts of cement and water, and where large cavities had to be filled fine sand was added.

At the beginning of each operation, a pressure of 25 pounds per square inch was applied to the grout, which was increased with subsequent batches of grout until 100 pounds was reached, when the hole was finished.

Alternate holes in the up-stream row were first drilled, these being 6 feet apart, and after testing for leakage were grouted.

A few holes at wide intervals in the second row were drilled and tested to try the efficacy of the grouting of the up-stream row. As a result only a few holes were grouted in the second row. It was found that the grouting of the upper row made

the drilling of the lower distinctly easier, by eliminating the tendency to cave.

Average Leakage Under Pressure Test and Average Amount of Cement Used in Grouting

	Leakage Gallons Per Minute Per Boring	Sacks Cement, Average per Boring
Primary holes (18) 1st section	33.1	10.3
Secondary " (17) 1st "	5.5	12.7
Primary " (10) 2d "	71.5	42.3
Secondary " (10) 2d "	28.3	17.6
Tertiary " (11) 2d "	11.2	4.5
Second tertiary holes (11) 2d section	6.4	3.7

Cost of Grouting Lahontan Cut-off

Linear feet of cut-off treated	220
Number of holes drilled and grouted	83
Average depth of holes drilled and grouted, feet	32
Total depth of holes drilled and grouted, feet	2,593
Total sacks cement used	1,174
Total cost per foot of hole	$ 3.57
Total cost per foot of cut-off wall	42.12
Total cost of boring and grouting	9,267.17

The material adopted was a combination of silt and gravel. A mixture of these, found to be nearly impervious, was used for the water face, and gravel was used for the down-stream portion, the line of demarkation between the two materials being on a 1 to 1 slope from the center of the crest toward the up-stream toe.

The main dam has a top width of 20 feet, a water slope of 3 to 1 protected by 12 inches of gravel and 2 feet of hand-placed rock. The down-stream slope is 2 to 1, and is covered by 15 inches of quarry run of rock.

The maximum height of dam is 129 feet, maximum base thickness 660 feet, and a crest length of 900 feet, or 1,400 feet, including spillways.

A spillway 250 feet long is provided at each end of the dam. The spillways converge by means of guide walls, and descend on concrete steps to a central pool in the river-bed below the dam, where the two spillways discharge toward each other, destroying their energy in the pool, from which the water flows

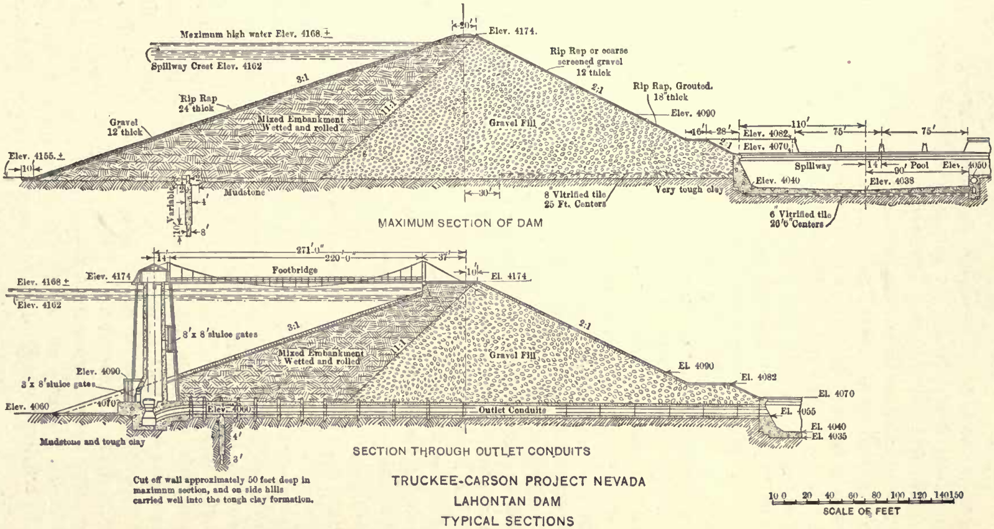


FIG. 74.—Sections of Lahontan Dam, Carson River, Nevada.

quietly down the river. The highest flood in the record of twelve years is about 20,000 cubic feet per second. This quantity of water would flow over the weir at a depth of 5.5 feet. The top of the embankment is 12 feet above the lip of the weir, and the area of the reservoir of 12,000 acres would have a large regulating effect on any flood, so that it is believed that a flood might occur of three times the above recorded volume without damage to the embankment.

Power-Plant.—The Truckee Main Canal reaches Lahontan at an elevation about 125 feet above the river-bed, and advantage was taken of this fact to develop power for construction purposes by dropping a portion of its water through turbines below the dam site. Two alternators of 625 KVA. normal rating each were installed, and furnished light and power for the work. They were actuated by two 24-inch turbines of 830 horse-power capacity each, operating under 110-foot head.

The current is generated at a pressure of 2,300 volts and was used in motors at 440 volts for actuating drag-line scrapers, loading sand and gravel for construction purposes, and hoists and other machinery connected with the work.

The power-plant was designed as a permanent installation to be used for pumping and commercial purposes, and has since been leased for such use and enlarged by the addition of a third unit of the same capacity as the others.

Sand-Cement.—The spillways, outlet works and other concrete structures required a total of about 60,000 cubic yards of concrete.

As Portland cement required a long, expensive railroad haul, some experiments were made to determine the suitability of local materials for the manufacture of sand-cement. The fine silt found in abundance on the mesa north of the dam site proved to be well adapted for this use, and was so fine as to be suitable after screening for direct mixture with the cement for the final grind through a tube mill. On account of the dryness of the climate no dryer was installed, and this led to some annoyance at times after a rain, so that the economy of this omission is doubtful. The capacity of the mill was about fifteen barrels per hour. It consisted merely of a tube mill and some conveying machinery.

It was the aim to so mix the cement and silt that the quantity

of cement would be slightly greater than of silt, in order that no local inequality should turn the proportion the other way.

Good results were obtained with this sand-cement, but it was found to harden more slowly than Portland, so that forms could not be removed as early, which tended to neutralize the economy. For this reason on some of the work requiring most forming, Portland was used instead of sand cement. A net estimated saving of $12,000 was the result of the use of sand-cement on this work. In general, it may be said that sand-cement is adapted only to large, massive structures like concrete dams, where the forming is relatively small and the yardage very large.

Cableway.—For handling materials and equipment, a cableway was installed having a span of 1,600 feet. It was mounted on travelling towers 104.4 feet high, running on tracks parallel to the river, 800 feet long, equipped with 80-pound rails. The diameter of the cable is 2¼ inches and its capacity 10 tons. It was equipped with a 300-horse-power motor using alternating current at 440 volts. The hoisting speed was 25 feet per minute and carriage speed 1,200 feet per minute.

The building program provided for the construction, during the first year, of the cut-off curtain wall and the grouting of its foundation, the construction of the outlet conduit and of the circular spillway pool at the lower toe of the dam, and also for the preparation of foundation and the construction of the main embankment to the top of the wall of the spillway pool, which is a little above the outlet conduit. This involved a large amount of work, and left the work in a position to safely pass through a flood season, the water passing mainly through the outlet, and any excess flowing over the bank held in place by the wall of the spillway pool.

As soon as the first flood season was past, the work was pushed on the embankment, with the river flowing through the outlet conduit, and before the next flood season the bank had reached an elevation above the bench on the left bank which served as a foundation for the left spillway. Work on this spillway had meantime been pushed and the concrete was placed in condition to safely pass the water of the second flood season if it should exceed the capacity of the outlet works.

After the second flood season was past, the whole work was

pushed to completion as fast as possible, and was successfully completed without damage from floods.

Excavation.—Nearly all the excavation except the cut-off walls was performed by two 35-ton revolving traction steam shovels, with dippers of 1¼ and 1½ yard capacity, loading material into dump cars. All rock was blasted ahead of the shovels, which each averaged about 400 cubic yards per working day.

The silt, sand, and gravel used in the dam and concrete structures were obtained from the smooth country to the north of the dam, and at an elevation above its top. The gravel pit had to be stripped of a blanket of overlying silt, which was done with a 56-ton electric drag-line scraper, with a 1½-cubic-yard bucket, 60-foot boom and capacity of 100 cubic yards per hour. It was equipped with a 95-horse-power main motor, and 50-horse-power swinging motor, all motions being air-controlled.

A 60-ton electric shovel was used for excavating the gravel for the main dam. The swing and thrust were each operated by a 50-horse-power motor, and the hoist by a 115-horse-power motor, all actuated by alternating current at 440 volts.

The materials were hauled from the borrow pit in 4-yard dump cars running on an endless circular track leading to the receiving bins near the left abutment of the dam. The bins for the dam materials had a capacity of 1,000 cubic yards and the one for the concrete materials 200 cubic yards.

A belt conveyor 18 inches wide, operated by a 35-horse-power motor, was used for conveying the concrete gravel from the bin to the screening plant. The gravel was screened to three sizes, the sand passing a ¼-inch screen, the fine gravel an inch screen, and coarse gravel held on the latter. The three sizes were collected in distinct piles beneath the screens, and under these a timber tunnel was constructed containing six adjustable measuring hoppers, two for each size of material. From these hoppers the aggregates were carried on another belt conveyor to the mixer. The cement bin was located over this same belt. The water for mixing was obtained by means of a gravity pipe line direct from the Truckee Canal. A boiler heated the water for use in cold weather.

The concrete was mixed in a 1½-yard mixer operated by a 30-horse-power motor. The mixer discharged directly into a 2½-yard bottom dump bucket on a flat car, two batches filling a

bucket. This car was hauled by a horse on a track parallel to the tracks of the cable tower and of equal length thereto.

A hopper tower was erected to receive the concrete from the dump bucket, and the concrete poured to place through a movable tubular spout. The hopper tower was moved from place to place by means of the cableway. All concrete was covered by burlap sheets and kept wet for 10 days. The concrete was generally proportioned as 1 part cement, $2\frac{1}{2}$ sand, $5\frac{1}{2}$ gravel well graded.

Embankment Materials.—The receiving bins for gravel and silt for the embankment were side by side, and had a 36-inch belt conveyor running lengthwise under the center line between the two bins, so that material could be discharged upon it from either bin. The material was fed to the belt by twelve reciprocating adjustable feeders, so that the gravel and silt could be proportioned as desired on the belt. This conveyor fed to a 30-inch belt at right angles to it, which carried the material 900 feet to a distributing bin in a central position on the dam, from which it was deposited by chutes into dump wagons and hauled to place.

The material was spread by Fresnoes in 3-inch layers, and rolled by two 10-ton traction engines. The gravel fill in the downstream portion of the dam was dry-rolled, while the tight portion of mixed silt and gravel was sprinkled before rolling. Adjacent to all hillsides and structures silt was used and well puddled.

The water slope of the dam was covered with 12 inches of gravel, and this was covered with 2 feet of hand-placed rock paving.

The rock was obtained about one mile from the dam, where a quarry was opened in a hill of basalt rock. Tunnels were run into this hill, and about 30,000 cubic yards of material loosened in one blast. One of the 35-ton steam shovels was used for loading the rock on flat cars, which were hauled to the dam on a narrow-gage track.

Outlet Works.—The outlet works consist of twin conduits of horseshoe shape, 9 feet in diameter, of heavily reinforced concrete.

Cut-off collars completely encircle the structure 3 feet deep and 18 inches thick at varying intervals to prevent seepage along the structure. The conduit is located along the left bank of the river, has a grade of 1 per cent, and is designed to carry 2,000

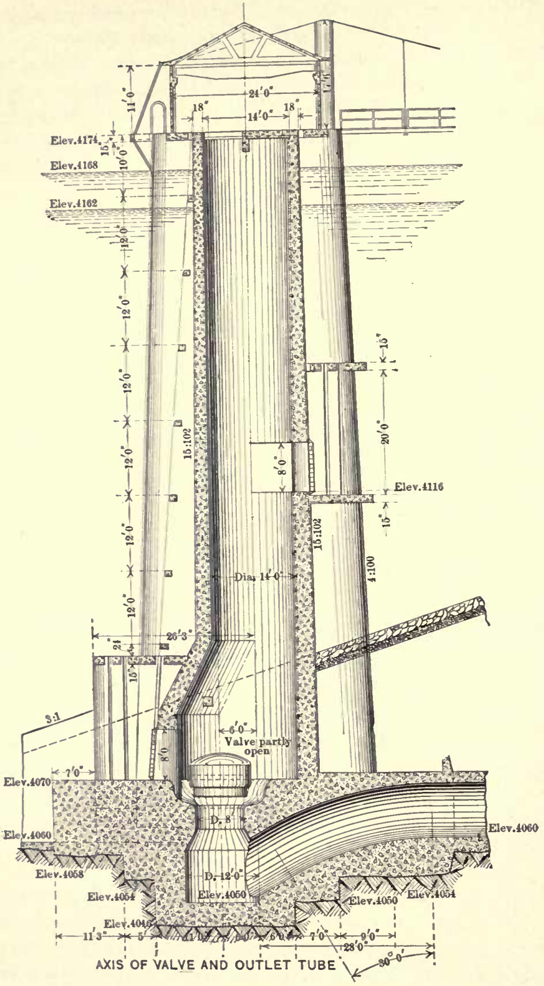


FIG. 75.—Outlet Works, Lahontan Dam, Carson River, Nevada.

second-feet of water. It discharges into the spillway pool at elevation 4,055.

The flow is regulated by a system of gates and valves installed

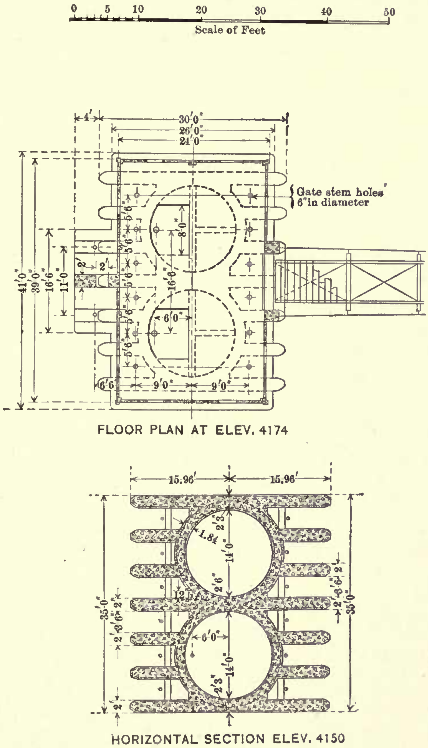


Fig. 75*a*.

in a gate tower near the up-stream toe of the dam on the left bank of the river. The tower is a double vertical tube of reinforced concrete, each tube being 14 feet in diameter.

At the head of each conduit is a curved cast-iron pipe or

"gooseneck," 7 feet in diameter, to change the direction of flow from the vertical drop in the tower to horizontal discharge into the conduit. At the top of this gooseneck is the main control valve, which works like a piston rod. The upper end of the vertical piston rod slides into a metal cap or dome about 9 feet in diameter and 3½ feet deep, rigidly attached to the tower by means of brackets. The piston rod is hollow, 8 feet in diameter and 3 feet long, and works up and down within the cap.

When the valve is closed the water pressures around the cylinder are balanced. As the piston rod is raised within the cap, the water rushes in uniformly around the circle, and falls down the "gooseneck" to the water cushion. Three sets of standard vertical lift gates are provided for admitting water to the tower. At elevation 4,060 are two $3' \times 3'$ sluice-gates, one to each valve chamber. Ten feet higher each tower is provided with three standard gates each 3 feet wide and 8 feet high. Another similar set of gates to each tower is provided 46 feet higher, or 46 feet below the spillway lip. Water is admitted to the tower at all times through the highest available gates.

The movement of the gates is accomplished by means of oil-operating cylinders, one for each gate, located in the tower house. An electric motor coupled to a triplex pump furnishes the power.

Each conduit is provided with an air duct $2' \times 3'$, just below the "gooseneck," extending to the open air above the reservoir, which admits air to the conduits and relieves the tendency to vacuum.

Directly over the cylindrical valves, and attached to the dome or cap, are 12-inch air pipes extending upward to a point above the high-water elevation. The supply of air to these pipes is regulated by slide-gates, and these need adjustment to changing conditions. Too much or too little air causes vibrations.

The outlet tower is connected with the top of the dam by a suspension foot-bridge 220 feet long.

The Truckee Main Canal discharges into the reservoir down a chute ending about 50 feet above the ground and 70 feet above the river-bed. The lower end of the chute is built as a cantilever, and is turned slightly upward to project the water to the maximum distance away from the fou dations of the chute. Under the fall was built a concrete apron, and the vicinity riprapped with rock.

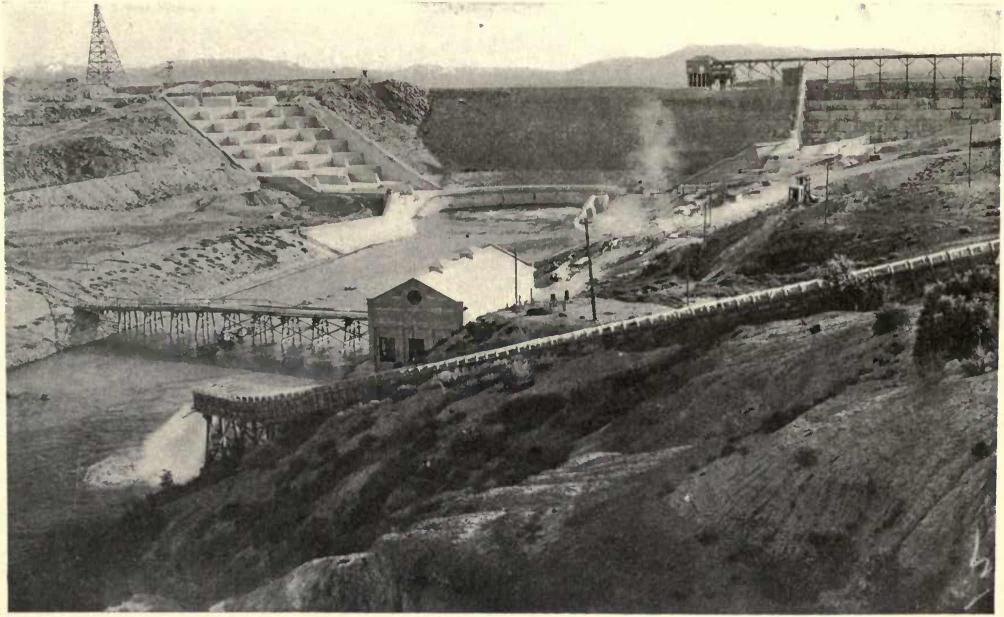


Fig. 76.—Lahontan Dam, looking up-stream, Carson River, Nevada.

A reinforced concrete pressure pipe, 6 feet in diameter, crosses the river just below the dam, forming part of the structure of the spillway pool, connecting the Truckee Main Canal with the high bench lands on the opposite side of the river. It has a maximum head of 140 feet.

A power pipe 4 feet in diameter connects the power-house with the reservoir at elevation 4,140, passing through the dam immediately to the north of the left spillway. This can be used to supply water to the power-plant in case of a shut-down of the Truckee Canal.

Lahontan Dam—Truckee-Carson Project, Nevada

Items	Quantity	Unit	Total Cost	Feature Cost
Main Dam, excavation, C.Y.	11,318	1.70	$19,230.45	
Mixed embankment.....	346,377	0.56	194,770.69	
Gravel fill (embankment).	230,514	0.46	106,299.72	
" buttresses........	24,920	0.44	11,056.67	
" under pavement..	10,116	0.61	6,190.69	
Paving, Class 3.........	24,548	3.13	76,792.59	
Miscellaneous...........	......	.....	674.51	$415,015.32
Cut-Off, excavation (chan.).	19,417	0.84	16,291.92	
Excavation, (trench).....	7,701	4.94	38,009.97	
Concrete, Class E.......	4,877	7.25	35,407.05	
Backfilling..............	3,490	2.03	7,068.58	
Grouting under wall.....	......	.....	9,227.24	106,004.76
L. Spillway, excavation.....	100,060	0.71	71,148.19	
Concrete, Class A and B..	23,319	8.05	187,424.73	
Backfilling..............	2,645	1.06	2,809.70	
Paving, Class 3.........	590	4.70	2,768.90	
" " 2.........	......	.....	....	
Reinforced steel (lbs.)....	345,061	0.03	10,048.07	
Miscellaneous...........	......	.....	2,002.20	276,201.79
R. Spillway, excavation....	57,080	1.17	66,854.23	
Concrete, Class A and B..	16,531	6.90	114,089.31	
Backfilling..............	5,760	1.05	6,080.12	
Paving, Class 3.........	773	4.11	3,180.92	
" " 2.........	......	.....	....	
Reinforced steel (lbs.)....	177,600	0.03	5,034.70	
Miscellaneous...........	......	.....	1,378.52	196,617.80
Spillway Pool, excavation...	35,142	1.18	41,353.64	
Concrete, Class A and B..	13,540	7.00	94,794.86	
Backfilling..............	1,628	0.78	1,265.18	
Paving, Class 3.........	555	6.86	3,803.65	
Reinforced steel (lbs.)....	42,930	0.04	1,818.89	
Miscellaneous...........	......	.....	1,712.05	144,748.27
River Channel, excavation...	17,500	0.69	12,003.05	
Backfilling..............	3,563	0.49	1,741.87	
Paving, Class 3.........	1,807	6.05	10,894.67	24,639.59
Outlet Conduit, excavation..	14,821	1.42	21,032.21	
Concrete, Class C.......	5,949	8.66	51,496.90	
Reinforced steel (lbs.)....	96,550	0.03	2,713.58	
Miscellaneous...........	......	.....	84.00	75,326.69

Lahontan Dam—Truckee-Carson Project, Nevada
Continued

Items	Quantity	Unit	Total Cost	Feature Cost
Outlet Tower,				
Concrete, Class 3........	2,689	14.29	$38,456.68	
Reinforced steel (lbs.)....	165,363	0.04	5,849.21	
Operating equipment (lbs.)	440,637	0.12	50,829.28	
Miscellaneous...........	......	.....	623.41	$95,758.58
Roadway, Concrete, bridges..	1,619	13.07	21,157.83	
Reinforced steel (lbs.)....	180,077	0.03	4,954.18	
Concrete roadway (lbs.)..	488	12.79	6,243.57	
Reinforced steel (lbs.)....	2,990	0.03	88.81	
Concrete railing	135	38.98	5,262.34	
Reinforced steel (lbs.)....	4,750	0.03	116.94	
Lighting system.........	......	.....	1,372.94	39,196.61
Suspension Foot-Bridge,				
Concrete, Class A.......	180	14.17	2,551.83	
Reinforced steel (lbs.)....	2,201	0.03	70.28	
Steel bridge (lbs.).......	38,689	0.12	4,815.81	7,437.92
Lahontan Dike:				
Embankment...........	15,334	0.31	4,740.39	
Gravel covering.........	6,054	0.99	5,995.17	10,735.56
Chute Protection:				
Excavation.............	3,975	0.45	1,802.56	
Paving, Class 1.........	178	12.40	2,206.13	
" " 2.........	101	13.11	1,324.76	
" " 3.........	2,517	4.44	11,179.02	16,512.47
Miscellaneous:				
Water elevation (pool)...	......	.....	2,169.65	
Stream control..........	......	.....	15,247.02	
Reservoir roads.........	......	.....	514.40	
Reservoir (clearing)......	......	.....	3,406.72	
Truckee Canal Bridge....	......	.....	1,682.17	23,019.96
Lahontan Bench Unit:				
Excavation (siphon).....	2,564	1.15	2,939.66	
Concrete (siphon).......	660	20.73	13,679.75	
Reinforced steel (siphon), lbs..................	62,378	0.04	2,202.83	
Structural steel (siphon), lbs..................	......	.....	344.76	
Backfilling (siphon)......	1,215	0.95	1,159.91	
Excavation (canal)......	9,758	0.33	3,238.04	
Concrete (sq. yds) lining.	No lining	placed	212.30	23,777.25
Power Pipe Line, excavation.	3,445	1.35	4,649.54	
Concrete...............	686	18.98	13,552.05	
Reinforced steel (lbs.)....	62,853	0.03	1,993.79	
Structural steel (lbs.)....	......	.....	247.85	
Backfilling.............	2,450	0.53	1,298.21	21,741.44
Grand total (including general expenses) June 30, 1915..				$1,476,734.01

CARSON DIVERSION DAM

The diversion works about five miles below the Lahontan Dam closely resemble those on the Truckee, just described; the principal difference being due to the foundation which, instead of gravel and boulders on the Truckee, is sand and silt and some gravel on the Carson.

The dam is 225 feet long between abutments, and has 23 openings of 5 feet each, closed by cast-iron gates of design similar to those in the Truckee Dam.

The foundation rests upon round, wooden piling spaced in 7-foot centers both ways, and capped with a grillage of 12 × 12 timber, 3 feet high, 31 feet wide, and 240 feet long. The piles were driven to refusal, usually 12 to 14 feet. At the upper edge of this grillage a row of Wakefield sheet piling was driven, and a similar row of sheet piling was driven at the lower edge.

Two canals head from the Carson Diversion Dam, the larger being on the right bank and having a capacity of 1,800 second feet. The gates to this canal are three, and each has a span of 17 feet and a height of 5. They are of the rising weir type, being lowered to admit water to the canal and raised to shut it out. A fixed concrete weir is placed across the canal at the river's edge, with its crest 3 to 4 feet above the river-bed and slightly above canal grade, and the gate slides up and down behind this, serving to increase the height of weir to any elevation up to the high-water line. The purpose of using this type of head-gate is to skim the top of the water in flood and thus admit the minimum quantity of sediment to the canal. The gates are built up of steel I-beams and plates, moving on roller-bearings in the cast-iron guides upon the piers. One similar gate is used by the smaller canal on the north side.

About 5.8 miles below the head-works the Carson main canal has a drop of 26 feet in its water surface, in passing from the bench to bottom-lands. The excess fall is concentrated at one point so that it may in future be used for power purposes, and the structure provided was designed with such use in view.

The canal is here enlarged into a concrete-lined forebay on the lower side of which a semi-circular weir is provided over which the water falls to a water cushion below.

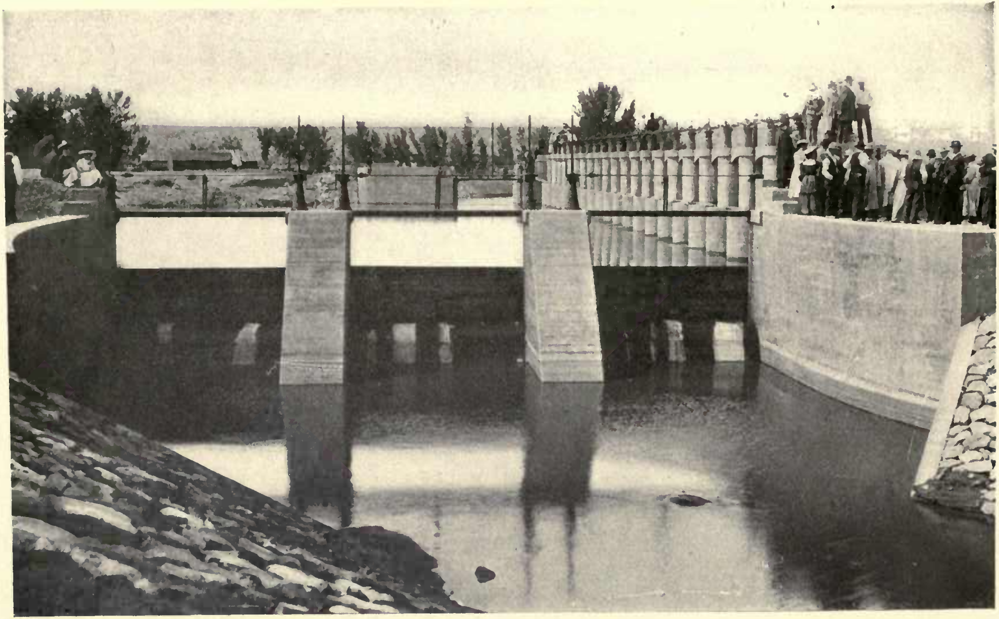


Fig. 77.—Head-works, Lower Carson Canals, Truckee-Carson Project.

Construction Costs Truckee-Carson Project

Headquarters and permanent buildings	$ 28,792
Main canals, Carson Valley	448,626
Lateral and Drainage system	1,408,432
Carson River Channel	131,821
Lower Carson diversion dam	91,725
Power-house drop	62,488
Examination general	123,733
Experiment Farm	7,008
Lake Tahoe Reservoir	17,307
Lahontan Reservoir	1,480,336
Main Truckee Canal	1,582,716
Truckee concrete chute	28,929
Rights of way and land purchases	168,595
Water right adjudication	17,078
Land surveys and maps	22,879
Telephone construction	42,210
Lahontan power plant	102,703
Commercial power system	26,504
Lahontan bench unit	19,557
Total construction cost to January 1, 1915	$5,811,479

The Truckee main canal and the diversion dams in the Truckee and Carson Rivers, as well as a large part of the distribution system, were built by L. H. Taylor, with J. H. Quinton as Consulting Engineer.

The Lahontan Dam and the Lake Tahoe regulating works were designed and built under direction of D. W. Cole.

CHAPTER XIII.

CARLSBAD PROJECT

DESCRIPTION

This system was built by a private corporation in 1891–3, and consisted of two reservoirs called Lakes Avalon and McMillan, both on Pecos River, and a system of canals on each side of the river.

Lake Avalon is formed by a combination earth and rock-fill dam built across the Pecos River in 1891, 48 feet high and 1,050 feet in length. The lower portion was of loose rock with down-stream slope of 1½ to 1, and the water slope of earth on slope of 3½ to 1, covered with stone riprap 2 feet thick. This dam serves primarily as a diversion dam, but has a storage capacity of about 5,000 acre-feet above the canal outlet, which is excavated in rock on the left bank of the river. The right side of the canal for a distance of 200 feet was closed by wooden gates to be opened in times of flood, and serve as a spillway. Two other spillways have been provided on the right or west side of the reservoir.

Lake McMillan is formed by a combination earth and rock-fill dam built across the Pecos River, 1,686 feet long and 52 feet high, and an embankment 5,200 feet long and 19 feet high, to close a gap in the hills west of the river. The section of the dam is similar to Avalon. The main spillway is cut through rock about one mile west of the dam and discharges into a ravine joining the river 2 miles below. In addition to this, a cut has been made in the hill still farther west, which discharges into the same drainage line, forming a secondary spillway which discharges only at higher stages of flood.

The canal branches 3 miles below the head-gates, the main canal crossing the river in a flume, and covering the main tract west of the river. The eastern branch continues down the valley and commands about 2,000 acres on the east side of the river.

The system as originally built is said to have cost over $2,000,000.

The Avalon Dam was overtopped by a flood wave in 1893, and destroyed. It was, however, quickly rebuilt by the company, and the second spillway on the west side was constructed. The system was placed in service by the company and the irrigated area gradually extended until 1904, when the company claimed to be furnishing water to nearly 11,000 acres. Serious defects in the works developed, however, making it impossible to furnish a reliable supply to this acreage.

The McMillan Reservoir adjoins on the east a bluff of gypsum, very soft and full of seams, and is partly underlaid by gypsum. It developed serious leaks, which gradually increased in magnitude by erosion and solution until caves and underground conduits were formed of such magnitude as to receive the entire flow of the river at ordinary stages. The capacity below the larger leaks was small, and it became impossible to fill the reservoir except in great floods, and the stored water was soon lost. The canal was also largely located in formations containing gypsum and the seepage losses were very serious and caused much damage to lands lying below. In one short stretch called "Gyp Bend" more than 100 cubic feet of water per second was lost in the gypsum cavities. In addition to this, the wooden structures soon showed the effects of decay, especially the high wooden flume across the river, which was replaced in 1903 by a structure of concrete, but much trouble was caused by the repeated failure of its approaches.

DESTRUCTION AND PURCHASE

In October, 1904, during a great flood, the Avalon Dam was again destroyed, both approaches to the concrete flume were washed out and one of its piers undermined; the dam serving as a canal crossing for Dark Canyon was destroyed, the canal breached in numerous places, and the entire system put out of service. Lake McMillan also suffered severely. The earth dike which had been provided to cut off the most serious leaks had been washed out, as had also the dam closing the gap in the hills on the west. The western spillway had so seriously eroded as to threaten the entire reservoir, and it was later permanently closed. Scarcely a structure or a mile of canal on the entire system was left in usable condition after the flood.

In this emergency the Secretary of the Interior was petitioned to purchase this collection of wrecks and undertake their reconstruction. Although hampered for funds on account of the large amount of work in hand, the Secretary did so in order to save from destruction an entire community.

RECONSTRUCTION

The remains of the canal and reservoir system were purchased in 1906, and the United States undertook to make such repairs and new construction as would place the system in service, leaving many desirable betterments and replacements for some future time when funds should become more plentiful.

Lake Avalon Dam was rebuilt with a reinforced concrete core-wall with earth embankment on the water side and rock-pitching on the down-stream side. Where a portion of the original earth bank remained adjacent to the left abutment, steel piling was driven instead of the core-wall. The provision of a core-wall was an innovation upon the usual Western practice, and especially that of the Reclamation Service. Its necessity arises from the presence of a large percentage of soluble salts in the earth available for embankment. In use, the slow percolation of water through such a bank gradually leaches out the soluble matter, leaving the bank more and more porous, and it soon becomes unreliable as a barrier against water. The core-wall is thus made necessary, and also serves the purpose of preventing destruction through the ravages of burrowing animals.

The large concrete flume, which carries the main canal across the Pecos River 5 miles below Avalon Dam, was repaired by carrying the foundations of its piers down to bed-rock, repairing the numerous cracks that appeared in its sides, and rebuilding the wing walls and approaches. The perfect service that this flume has given since its reconstruction, contrasted with frequent failures under the former management, testifies to the efficiency of the work upon it.

At Dark Canyon, where the former crossing had proved wasteful and inefficient, and had finally failed entirely, a substitute was adopted in the form of a 6-foot reinforced concrete pressure pipe, 400 feet long, crossing the canyon under a head of about 30 feet.

Black River is a small stream that flows into the Pecos from

the West, at the lower end of the project. Its waters are diverted by a canal on the right bank, to water about 1,000 acres of land. At times the waters of Black River are insufficient for this, and water is then furnished from the main canal of the project through a branch reaching Black River above the diversion point. The old canal from Black River was so leaky that it delivered only a small percentage of the water turned into it. The new canal is lined with concrete, and is practically water-tight.

The main canal of the project, as received by the Government, had no upper banks, and its water surface varied from 50 to 1,000 feet in width, and at drainage crossings had still greater width. So much porous ground surface exposed to the absorption of water produced enormous losses from the canal which did great damage where the water appeared on lands below. The banks of the canal were also porous in many places, due to the solution of salts by percolating water. They were also badly out of grade so that the water stood in pools or rushed over shoals.

This condition required the reconstruction of most of the main canal. In the lower course of the canal it passed through formations of gypsum so porous that it was necessary in places to abandon the location entirely, and build a new canal at a lower level.

The spillway gates in the side of the canal, just below the left abutment of the Avalon Dam, were rotten and unserviceable. As a temporary measure the Reclamation Service attempted to use this spillway with certain repairs, but it was found to be inefficient, and a permanent concrete lip was built in its place. In addition, two vertical wells were excavated in the solid limestone, joining two tunnels discharging into the river below. Each of these wells is protected by a cylindrical steel gate of similar design to the one controlling the inlet to the pressure tunnel on the Yuma Project. These gates are each 6½ feet high and 22 feet in diameter. Their tops are nearly level with the fixed spillway lip, so that when closed they act as automatic spillways, by allowing the water to flow over the top into the wells and out through the tunnel. In case of a heavy flood the gates are raised 10 feet, allowing the water to flow under them, and thus increasing both the cross-section and the discharge head by the height of the gates. Each gate is operated by a train of

gearing actuated by a turbine wheel. The capacity of spillway No. 1 is about 14,000 cubic feet per second.

Spillway No. 2 is a channel excavated through the natural rock, which is a fair grade of limestone on top, underlaid by strata of inferior hardness and much broken. Successions of floods have gradually eaten back into the channel, until it became necessary in 1912 to build a concrete lip on a semicircular arch, to serve as a spillway lip, and to protect the overfall by means of a heavy blanket of concrete.

This spillway has a rated capacity of 32,000 cubic feet per second.

Spillway No. 3, still further west, has a rated capacity of 22,000 cubic feet per second.

The repairs required by Lake McMillan, the main reservoir, were extensive and costly. To check the leakage from the reservoir, it was necessary to build a long dike, to exclude the gypsum caves along the eastern margin. The scarcity of earth near at hand, and the necessity of protecting the dike from wave action, led to the free use of limestone, which is convenient and abundant; the dike is 4,000 feet long and most of it is 19 feet high. The water slope is a retaining wall of hand-laid rock on a slope of ½ to 1, backed with earth. The outer earth slope is 2 to 1, and the earth toe is protected with rock riprap.

The failure of Avalon Dam in 1904 has never been satisfactorily explained. It was being watched at the time on account of the great flood, and it seems to be certain that the dam was not overtopped. The alternative theory that it was pierced by the hole of some burrowing animal seems improbable, in view of the scrutiny to which it is said to have been subjected shortly before failure. It is possible that the gradual percolation of water through the earthen bank had so leached out the soluble salts as to render it more and more porous and unsafe, and that the abnormal head upon the porous structure caused destructive velocities through its body, and consequent failure. The plausibility of the latter theory was the chief reason for providing the reconstructed dam with an impervious core-wall.

McMillan Dam was built on similar designs and with material similar to that used in the original Avalon Dam. It was visited by a great flood in 1914, and when the flood level was at its maximum a large leak was discovered by the patrol near the

west end. By prompt and energetic work with sacks and earth the dam was saved, and afterward thoroughly repaired. This occurrence lends further probability to the theory advanced to account for the last failure of Avalon Dam, in 1904, as the close inspection is inconsistent with the existence of holes made by burrowing animals, and the dam was certainly not overtopped.

The same flood in 1914 eroded the channel leading from the spillway west of the dam, and necessitated further repairs and protection thereto.

The Pecos River above Lake McMillan drains an area of 22,000 square miles. The stream is nearly dry at times, and is subject to violent floods, reaching in 1915 a volume estimated at 80,000 cubic feet per second. These floods are heavily laden with sediment, and of course this sediment is caught and largely held by the reservoir.

Careful surveys have been made to measure the amount of sediment thus received in the reservoir. This shows an average accumulation of about 4,000 acre-feet of sediment per annum. It is evident that in time other storage capacity will have to be provided.

DRAINAGE

The character of the soil through which the canals of the Carlsbad Project are largely built makes them porous in many places, as already explained. The soluble constituent is mainly gypsum, not specially harmful to the fertility of the soil, and in fact a certain preventive of carbonate of soda, which is the most destructive alkali known. The gypsum, however, slowly leaches out, and leaves the bottom and sides of the canals porous, and of course this causes water logging to the soils below. This and other conditions have made drainage works necessary. As a further precaution or preventive, the most porous parts of the main canal were lined with concrete to prevent percolation. In all, the Service has built 9 miles of open drains, and 4 miles of covered drains, at a total cost of $60,000. Fourteen miles of the Main Canal have been lined. and the cost of this work has been $75,000.

The reconstruction of the Carlsbad Project was planned and carried out by W. M. Reed, under the general direction of B. M. Hall as Supervising Engineer. The later betterments and the drainage were provided under L. M. Foster as Project Manager.

CHAPTER XIV

HONDO PROJECT

The expenditures of the Reclamation Service to June 30, 1916, were about \$106,000,000, of which \$360,000, or one-third of 1 per cent, were expended upon the Hondo Project in New Mexico. This project has been widely heralded as a failure, and comes nearer justifying that term than any other project undertaken by the service.

Its small size might justify us in passing it over as of little consequence, especially as the limited scope of this work requires the omission of several of the minor projects, and those in the early stages of construction. More profit, however, can sometimes be gained by studying the details of failures than of successful enterprises, and space will therefore be taken to describe the conditions from which lessons may be drawn.

DESCRIPTION

The Hondo River, so called, is a drainage line with about 100 square miles of tributary drainage heading in the Sierra Blanca group of mountains, containing the highest peak in New Mexico. The major portion of the drainage basin has the character of rolling plains upon which the precipitation is usually considerably less than 20 inches per annum. The river is usually dry or nearly so, but becomes a torrent under the influence of occasional heavy rains which occur in its basin. Only a small amount of irrigation can be carried on from the stream in its natural state, and any considerable increase requires the storage of water, which was undertaken by the Reclamation Service in 1904.

The storage reservoir is a natural basin, situated at some distance from the river. The unreliability of the water supply made it important that sufficient amount of storage capacity be provided to carry the project over two or three dry years in succession, and this in turn rendered important the probability of serious seepage from the reservoir. These facts, together with the

occurrence of extensive deposits of seamy limestone and gypsum in the neighborhood, indicated the importance of careful examination by a trained geologist regarding the probability of extensive leakage from the basin. Such an examination was made by a representative of the Geological Survey upon the request of the Reclamation Service, and as a result of this examination it was decided that there was no serious danger of important leakage from the basin, and construction was accordingly authorized.

By building between the surrounding hills earth embankments, six in number, of a height varying from 6.8 to 25.5 feet, and with a total length of 16,504 feet, the storage capacity of the reservoir was increased about fourfold, to the present capacity of 40,000 acre-feet. The flow of the Hondo is diverted by an earth dam 20 feet high and 100 feet long, and is led to the reservoir through a one-bank canal 8,275 feet in length and 70 feet in width at grade. This canal is designed to serve as a settling basin for the silt with which the flood waters of the Hondo are heavily laden, and with this in view its section is triangular, the side next to the embankment being excavated to a subgrade 4 feet below grade.

The lower bank is provided with two spill-gates and five sluice-gates, through which it is designed to scour out the accumulated silt as need requires, the silt-laden waters returning to the Hondo. The collection of silt in this canal is encouraged by a weir at its point of discharge into the reservoir, which permits only the upper third of the depth of water in the canal to enter the reservoir.

From the center of the reservoir the water is led to the Hondo River again, through a canal of 10 feet bottom width, 5,300 feet in length. The canal is crossed by one of the embankments, and the water is led under through two lines of iron pipe 3 feet in diameter. The inlet ends of these pipes are in a reinforced concrete tower reached from the bank by a steel foot-bridge. A platform at the top of this tower holds the ball-bearing stands operating the outlet-gates. After being returned to the Hondo, the water is conveyed down the river channel, a distance of about a mile, to the edge of the irrigated district.

The river-banks have been built up by the deposition of silt until they are higher than the surrounding country, and this permits ditches to be taken out almost at right angles to the course of the stream. Three low concrete diversion dams, each

containing a flash-board frame so arranged that it may be dropped to leave the river channel practically unobstructed, serve to throw the water into the four lateral canals. The slope of the surface is so great as to require the construction of frequent drops in these ditches to hold them down to a grade low enough to prevent a cutting velocity. These drops and all similar structures, head-works and the like, are of concrete.

When the reservoir was placed in commission it was found that considerable leakage occurred and the quantity of this rapidly increased by the enlargement of holes in the bottom of the basin which evidently connected with subterranean caverns of great capacity and extent.

Repeated efforts were made by puddling to prevent this leakage, and these were kept up for some years in the hope that the muddy water of the Hondo and the work of puddling would improve conditions and permit the storage of water in the basin, but this has not been the result. On the contrary, the leakage appeared gradually to increase in spite of all efforts until it reached a maximum of about 200 cubic feet per second, and efforts at storage were consequently abandoned. The canal system is still in use for irrigating such land as can be served by the unregulated flow of the creek, but this is so meager and uncertain that results are very small.

The Pecos Valley and vicinity for long distances above and below this point is largely of gypsum formation, and extensive leaks have developed in the reservoir built near Carlsbad in gypsum formation by the Pecos Irrigation Company. It is the author's opinion, not as a geologist but as an engineer, that the depression which constitutes the reservoir site of the Hondo project was formed by the percolation of underground waters through great deposits of gypsum and the gradual solution and erosion of those deposits until extensive caves were formed, which finally collapsed under the weight of the overlying earth and caused a depression or dry lake which formed the site for the reservoir adopted. The lesson is that natural depressions, situated at a distance from natural drainage lines, should be regarded with suspicion, especially when occurring in rock in which caverns may be expected to occur.

CHAPTER XV

RIO GRANDE PROJECT

DESCRIPTION

The Rio Grande del Norte rises in Colorado and flows southward the entire length of New Mexico. For a distance of 4 miles above El Paso it forms the boundary between Texas and New Mexico, and for about 1,300 miles to the Gulf of Mexico it forms the boundary between Texas and Mexico.

Above El Paso it has a length of about 900 miles, and a drainage area of 38,000 square miles. The basin in Colorado and northern New Mexico is largely mountainous, and the water supply being mostly from melting snow has the characteristics of such a supply, the high water season being in spring and early summer when the snows are melting, and the lowest stages occur in autumn and winter.

The major portion of the New Mexico drainage area is arid and desert in character and the meager precipitation is erratic and often torrential in occurrence.

The permanent summer flow from the mountains is entirely appropriated and used for irrigation in Colorado and northern New Mexico, leaving for the southern portion of New Mexico little more than the torrential floods occurring at irregular intervals.

This was not always the condition, however. The large irrigation systems of Colorado are of recent construction, and the area they irrigate is very large. The El Paso Valley was irrigated over 300 years ago, and when the Spaniards occupied the valleys of Central New Mexico in the sixteenth century, they found them irrigated by the Pueblo Indians living in towns and cultivating the land. This development was extended by the Spaniards and other settlers until the diversion of the water supply above caused a reversion to desert of some of the lands. As a result of this condition the river frequently went dry at El Paso, and at times remained so for months. The irrigated lands of the Rio Grande Valley both in Mexico and Texas re-

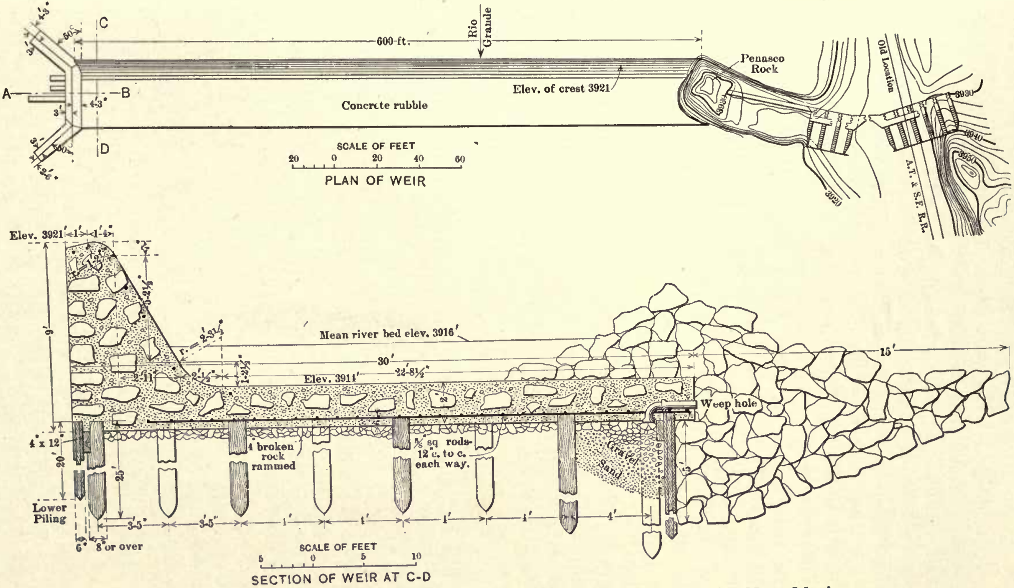


FIG. 78.—Leasburg Diversion Dam, Plan and Section, Rio Grande, New Mexico.

verted to desert for the most part. The Mexican lands of this class were estimated at from 20,000 to 25,000 acres, and on their behalf, the Mexican Government filed claims against the United States amounting to many millions of dollars, as compensation for damages suffered by the landowners of this valley.

For many years past the irrigation of 30,000 to 40,000 acres of land in the valley of the Rio Grande in southern New Mexico has been attempted, but the water supply was so precarious that crops could not be anticipated with any certainty. Often the river was dry for months at a time, and when a freshet came, it usually washed out the temporary dams of rock and brush that were employed, and which could not be rebuilt until the flood subsided. After its reconstruction at great labor, the river was perhaps dry again, or nearly so, and farming was often a failure.

Permanent dams were required at the head of each of the small valleys, and in 1906, a contract was let by the Reclamation Service for a diversion dam at Penasco Rock, above the old town of Leasburg.

LEASBURG DIVERSION DAM

The Leasburg Dam is a concrete overflow weir of ogee section, about 9 feet high and 600 feet long with an extension of 1,500 feet at the west end in the form of an earthen dike. The concrete weir is founded on piling driven into the silt of the river-bed to a depth of 20 to 25 feet. A reinforced concrete apron, 23 feet wide and 2 feet thick, receives the falling water as it flows over the weir and conducts it harmlessly away from the dam. A row of Wakefield sheet piling under the heel serves to prevent underflow. A similar row under the down-stream edge of the apron is designed to prevent backlash. A bed of sand and gravel just above the toe of the apron serves to collect drainage water, and should pressure be developed, it is relieved by drain pipes set in the concrete and discharging below. The lower edge of the apron is further protected by a mass of loose rock extending 5 feet below the natural river-bed, and 3 or 4 feet above and reaching down-stream for 15 feet or more.

The west abutment of the dam is founded on piling where it joins the earthen dike. The east or left abutment is founded on rock, the base of "Penasco Rock," a small peninsula of rock

jutting out into the river channel. About 80 feet inland from the end of the dam three sluice-gates are placed, each 8 feet high with 5 feet clear opening. Fifteen feet inland from these gates are the gates to the canal, of which there are five, each 7 feet high with 5 feet width of opening. The sluice-gate sills are about a foot lower than those of the canal gates. Owing to the desirability of building the canal head-gate structure and the sluice-gate structure both on bed-rock, it was not possible to place them at an angle of 90 degrees, which is the angle of greatest sluicing efficiency. The angle between the axes of the structures is about 150 degrees but, nevertheless, the sluicing results have been fairly satisfactory.

ELEPHANT BUTTE RESERVOIR

The International Boundary Commission worked out a project designed to store the waters of the Rio Grande by building a dam just above the city of El Paso, to furnish a supply of stored water to the lands of the El Paso Valley on both sides of the river, amounting to about 50,000 acres, of which more than half was on the Mexican side.

This project, however, did not utilize the entire flow of the river, lacking both storage capacity and irrigable land, and it furnished no water for irrigating land in New Mexico, although the reservoir would submerge a large acreage in that State. In consequence the project was violently opposed by the people of New Mexico, and a better solution of the problem was sought by the author.

The conditions to be met in providing storage on the Rio Grande are extreme and are mainly as follows: While the floods on the river are enormous, they do not come with any regularity, and the total flow in some years is less than one-twelfth of that in other years. The amount of silt carried by the river is very large, especially in flood, and would be caught and held by any reservoir, irrespective of its size. Hence the silt problem is relatively far more acute with a small reservoir than with a large one.

For these reasons it is imperative that the reservoir be as large and deep as possible, so as to minimize evaporation, to have ample capacity for holding the waters from years of large supply for use in years of drouth, and a surplus capacity for silt accumulations, so that the sediment will not materially encroach upon the necessary water-storage capacity for many years.

A reconnoissance by the author in May, 1902, indicated the feasibility of building a high dam in the canyon about half a mile below Elephant Butte, to form a reservoir about 40 miles long with a capacity of over 2,000,000 acre-feet, which would cover about 40,000 acres and would not submerge any railroad, nor any large body of good land.

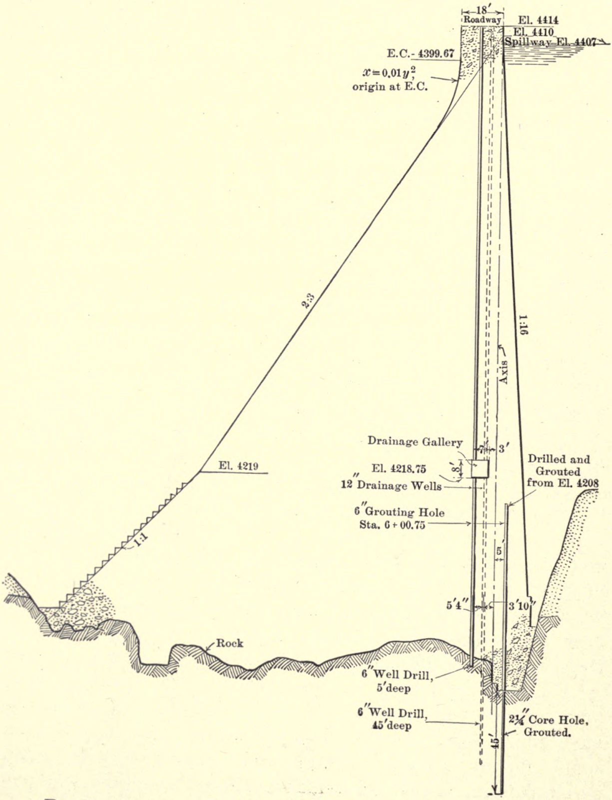


Fig. 79.—Section of Elephant Butte Dam, Rio Grande, N. M.

After the passage of the Reclamation Act, surveys were made of the reservoir site, and the following areas and capacities were ascertained:

AREA AND CAPACITY OF ELEPHANT BUTTE RESERVOIR

Elevation above Sea-Level, Feet	Depth of Water, Feet	Surface of Water, Acres	Capacity, Acre-Feet
4,210	0	0	0
4,215	5	41.5	110
4,220	10	130.5	415
4,225	15	219.5	1,290
4,230	20	365	2,610
4,235	25	511	4,825
4,240	30	843	7,720
4,245	35	1,175	12,765
4,250	40	1,781	19,470
4,255	45	2,388	29,890
4,260	50	3,145	43,350
4,265	55	3,908	58,470
4,270	60	4,664	82,375
4,275	65	5,426	107,600
4,280	70	6,175	136,635
4,285	75	6,924	169,385
4,290	80	7,630	205,880
4,295	85	8,335	245,795
4,300	90	8,977	289,235
4,305	95	9,620	335,730
4,310	100	10,550	385,435
4,315	105	11,480	440,510
4,320	110	12,553	500,240
4,325	115	13,626	565,685
4,330	120	14,811	635,500
4,335	125	15,996	713,515
4,340	130	17,618	796,465
4,345	135	19,241	888,615
4,350	140	21,370	988,875
4,355	145	23,499	1,101,045
4,360	150	25,516	1,223,065
4,365	155	27,534	1,355,690
4,370	160	29,553	1,500,000
4,375	165	31,600	1,657,000
4,380	170	33,800	1,828,000
4,385	175	36,000	2,014,000
4,390	180	38,200	2,216,000
4,395	185	40,400	2,435,000
4,400	190	42,600	2,672,000*
4,405	195	44,800	2,928,000
4,407	197	45,680	3,035,000†
4,410	200	48,000	3,204,000
4,414	204	49,760	3,400,000‡

* Full reservoir, normal.
† Spillway lip.
‡ Top of dam.

Diamond drill borings were made on several alternative lines in the river-bed and test pits were opened and examined on the abutments.

After the feasibility of this project had been demonstrated, an arrangement was made with the Republic of Mexico whereby the United States undertook to construct a large reservoir to store the Rio Grande waters, and to deliver to Mexico at the Acequia Madre, the Mexican canal at the head of El Paso Valley, 60,000 acre-feet of water annually, and Mexico on her part waived all claims to indemnity for the adverse diversion of Rio Grande waters. A subsequent Act of Congress extended the provisions of the Reclamation Act to the State of Texas and, later, an appropriation of $1,000,000 was made to cover Mexico's share of the Reservoir.

It is estimated that an abundant supply for all the land that can be reached by gravity from the various favorable diversions in the valleys below Elephant Butte, which is about 155,000 acres, will require about 4 feet in depth on the land, or 620,000 acre-feet annually, including all losses. Treaty obligations require the delivery of 60,000 acre-feet annually to the Republic of Mexico at the head of the Acequia Madre in El Paso. Allowing 20 per cent loss on all water turned out for this purpose, it will require 80,000 acre-feet, or a total draft on the reservoir of 700,000 acre-feet, per annum.

The records of the past twenty years show how the water supply would have fluctuated under the proposed conditions had they been in operation during that time.

Elephant Butte Dam.—This dam is a straight gravity structure built of cyclopean concrete. Its length is about 1,200 feet, and its height from lowest foundation to the roadway over the top is about 300 feet, over 90 feet of which is below river-bed, and the top width is 20 feet. The up-stream face of the dam has a batter of 1 to 16, and the down-stream face has a batter of 2 to 3, to the river-bed, below which the batter is 1 to 1.

A spillway lip 400 feet long is provided at the west end, at elevation 4,407, or 7 feet below the roadway. In addition to this lip spillway, a movable spillway is provided, consisting of four large wells, 10 feet in diameter in the rock bench just upstream from the spillway lip, the bench being at elevation 4,396. Each well is closed by a steel cylinder gate which can be raised

Elephant Butte Reservoir—Showing Results If It had Been Operated for the Past Twenty Years with Annual Draft of 700,000 Acre-Feet, Beginning 1896

Year	Inflow	Accumulated Silt	Evaporation	Waste	Stored Water
1895	1,259,234	22,666	123,700	0	1,112,869
1896	554,855	32,653	161,213	0	796,524
1897	2,215,953	72,540	209,677	0	2,062,913
1898	960,981	89,838	289,170	0	2,017,426
1899	239,434	94,148	247,212	0	1,305,338
1900	467,703	102,567	191,684	0	872,938
1901	656,252	114,380	151,697	0	665,680
1902	200,729	117,993	103,445	0	59,351
1903	1,272,069	140,890	111,696	0	496,827
1904	709,796	153,666	94,838	0	399,009
1905	2,422,008	197,262	238,935	0	1,838,486
1906	1,563,917	225,413	286,062	245,163	2,143,077*
1907	2,157,529	264,249	296,011	1,161,518	2,104,241*
1908	774,109	278,183	287,458	55,800	1,821,158
1909	1,279,934	301,222	286,595	24,180	2,067,268*
1910	852,692	316,570	281,685	343,185	1,579,742
1911	1,799,733	348,965	280,954	346,591	2,019,525*
1912	1,499,614	375,958	291,368	717,530	1,784,250
1913	525,443	383,396	264,104	0	1,338,151
1914	1,093,701	402,083	228,986	0	1,484,179

*Full reservoir.

The above table assumes that the inflow of silt is 1.8 per cent of the total inflow; that the United States Project of 155,000 acres will require 3 acre-feet per annum at the land and 60,000 acre-feet will be delivered at the Mexican Dam at El Paso every year for Mexican use; that the losses in river and canal will be 25 per cent of that turned out of the reservoir and that the annual evaporation minus the precipitation is 6 feet in depth per annum from the reservoir. Capacity is taken as 3,000,000 acre-feet of which 330,000 is reserved for flood control, leaving 2,670,000 acre-feet available for storage.

and lowered at will. Each well merges into a tunnel which passes under the spillway lip and discharges into the spillway channel below. The purpose of the movable spillway is to provide a means of regulating the discharge of the spillway within the volume that can be safely carried without damage, by the river channel below. When the reservoir reaches an elevation of 4,400, or 7 feet below the lip of the spillway, the gates can be opened and will discharge at that stage about 4,000 cubic feet per second, and an equal amount can be drawn through the service gates. If the river is discharging more than this, the reservoir will continue to rise, and by the time it reaches the spillway lip, the

discharge through the cylinder gates will be about 6,000 cubic feet per second, and through the service gates 2,000 cubic feet per second. As it continues to rise, and the discharge is aug-

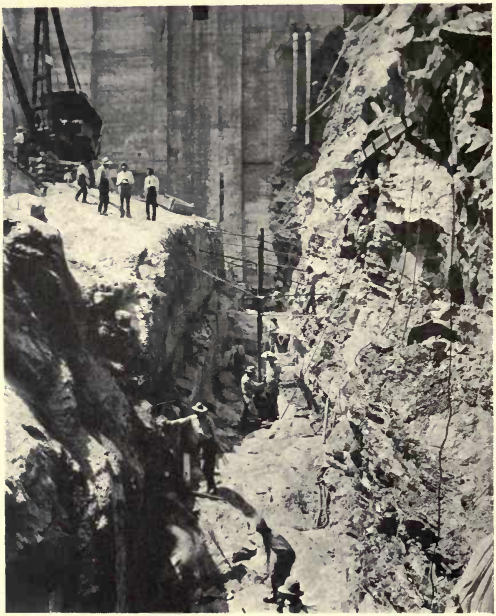


Fig. 80.—Cut-off Trench, Heel of Elephant Butte Dam, Rio Grande Project.

mented by the flow over the lip, the gates will be gradually closed sufficiently to hold the discharge to about 8,000 cubic feet per second, and this amount will not be much exceeded according to records now available. In case a flood occurs in the tributaries below the dam while the spillway is discharging, it can be closed until that flood has subsided, and thus the flow in the river channel confined to a safe quantity.

For drawing water from the reservoir, twelve outlets have been provided. Those nearest the left bank are provided primarily

for use in connection with penstocks for the development of power at some future time, by means of the water drawn from the reservoir. Of these there are two sets of three gates each, the lower set at elevation 4,234 and the upper set at 4,264.7. The gate openings are $4' \times 5'$ connected by transition castings to 5-foot diameter cast-iron pipe. West of these, at elevation 4,234, are two rectangular conduits of rich concrete, each controlled by two slide-gates, one for regular use and the other for emergencies, in case of accident. These openings are called the sluicing tunnels. West of these, in a buttress or projection built up-stream from the face of the dam, are the four main service gates. These are of the sliding type with clear openings of 4 feet by 7½ feet, two being at elevation 4,221 and two at 4,259.7. The water passing through these gates is discharged into internal wells or chambers, from which it is drawn by balanced valves, of which there are four, two at elevation 4,234 and two at elevation 4,290. They regulate the flow through circular concrete conduits 5 feet in diameter, discharging under water at elevation 4,212.

All gate entrances are provided with grooves extending to the top of the dam, in which a heavy steel shutter can be placed to close the opening and permit access to the up-stream gates when necessary for inspection or repairs. Internal operating chambers are provided and all operating mechanism is well lighted and easily accessible under all conditions. The sliding gates are operated by hydraulic power, water being furnished from the large supply tank on the hill which was used during construction.

The balanced valves are similar in design and operation to those used in the Arrowrock Dam, described on page 119.

The total weight of the controlling mechanism was over 1,000 tons, the heaviest single pieces being portions of the balanced valves, which weighed 23 tons each.

The buttress or tower which carries the service gates and balanced valves is flanked by a screening tower of reinforced concrete with openings designed to admit water and exclude drift. That portion of the screening tower protecting the penstock and sluice-gates extends to elevation 4,272, and that in front of the service gates is carried up to 4,370.

A variety of precautions was adopted to prevent percolation into and under the dam, and to relieve any upward pressure that might develop there.

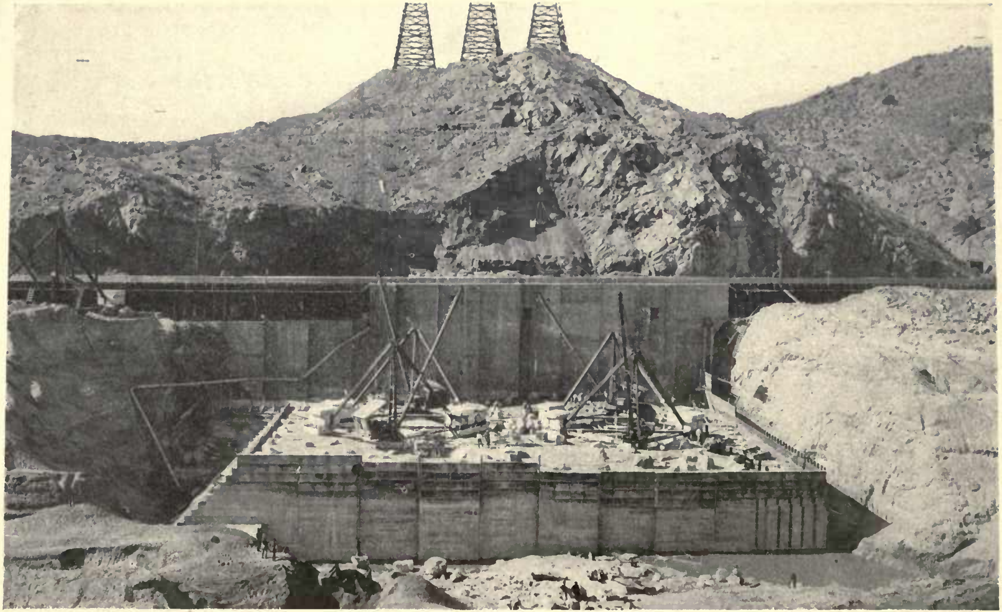


FIG. 81.—Diversion Flume and Foundation, Elephant Butte Dam, Rio Grande, New Mexico.

A cut-off trench was provided at the heel of the dam, averaging about 10 feet wide in the bottom and 15 feet deep below the balance of the foundation, and filled with rich concrete. The bottom of the trench was left always in excellent sandstone. A row of holes was provided in the center of the cut-off trench at 10-foot intervals, extending 50 feet below the bottom of the trench, into which cement grout was forced under high pressure to seal all accessible seams and prevent percolation under the dam. In all, 147 holes were grouted, requiring 254 barrels of Portland cement and 640 barrels of sand-cement. One hole took 56 barrels.

About 10 feet down-stream from these grouting holes, another row of holes, or drainage wells, 6 inches in diameter and 8 feet apart, was provided the entire length of the dam and continued upward to the drainage tunnel, or gallery, located a little above the river-bed, which will discharge any water received into a cross conduit leading to the down-stream face of the dam. These drainage wells were drilled to a depth of 45 feet below the base of the dam. Their purpose is to intercept any percolation beneath the dam not cut off by the grouting and to relieve any pressure that might otherwise occur. They can, of course, be grouted later if this be deemed best. Five feet down-stream from the first line of drainage wells, a similar line of wells was provided, alternating with the first line, not extending into the natural rock but leading up into the drainage gallery. All the drainage wells were continued upward from the drainage tunnel to near the top of the dam, with diameters of 12 inches.

In order to reduce percolation from the reservoir into the body of the dam, the portion of the up-stream face, about 5 feet in thickness, is made of a richer mix than the balance of the dam, and the entire water face of the dam was coated with cement mortar applied with a cement gun. The mortar was composed of one part Portland cement and two parts sand, and applied in four layers, each about ¼-inch in thickness. The wall was first cleaned with wire brooms and then roughened with a sandblast to secure proper adherence of the mortar.

The stone for the masonry of the dam was obtained from three sandstone quarries located along the railroad track from 2,000 to 6,000 feet from the dam. Five quarries in all were opened, but only two gave results at all satisfactory, and even

these have considerable waste in the form of shale and other unsuitable material. Ten guy derricks were used in the quarries.

Construction of Elephant Butte Dam.—This structure is built of concrete, with large stones imbedded therein to the extent of from 20 to 25 per cent. Its solid contents are in excess of 600,000 cubic yards. It is founded on rock in place, which is about 100 feet below the river-bed in places. It consists of alternate strata of shale and sandstone, neither of which is very hard, and which are much folded and broken. The shale disintegrates rapidly on exposure to air, and it was necessary to clean off all surfaces of that material just before depositing concrete.

Three cableways were installed for excavation and construction purposes, each with a clear span between towers of about 1,400 feet. The cables were 2¼ inches in diameter and had a normal capacity of about 8 tons; each was operated by a 300-horse-power electric motor.

The necessary power for the operations was provided by a plant of three steam turbines directly connected to alternating current generators of 625 kilowatts capacity each, furnishing current at 2,200 volts, at which tension it is transmitted about the work and used by the cableways and the larger motors, but it is stepped down for the smaller motors. The coal used in this plant was passed through a coal breaker and fed by automatic stokers to furnaces under vertical boilers. An air compressor furnished air for drilling purposes in the quarry.

For the transportation of men and materials of construction, a standard-gage railway was constructed, connecting the Santa Fe route with the dam site. The road is 11 miles in length and has a maximum grade of nearly 4 per cent.

The water supply for the camps and for boilers and construction purposes was obtained from wells sunk in the sands of the river-bottom. It was pumped by electrically driven triplex pumps to a 300,000-gallon concrete tank about 400 feet above the river. The water was piped from this tank to the power-plant and the concrete mixers and also to the upper camp. It also furnishes the hydraulic power for operating the slide-gates in the dam.

The river was diverted during construction through a flume built on a bench excavated on the right bank. Where the flume crossed the dam site it was built of concrete, and finally incorporated with the dam. The rest of the flume was of lumber;

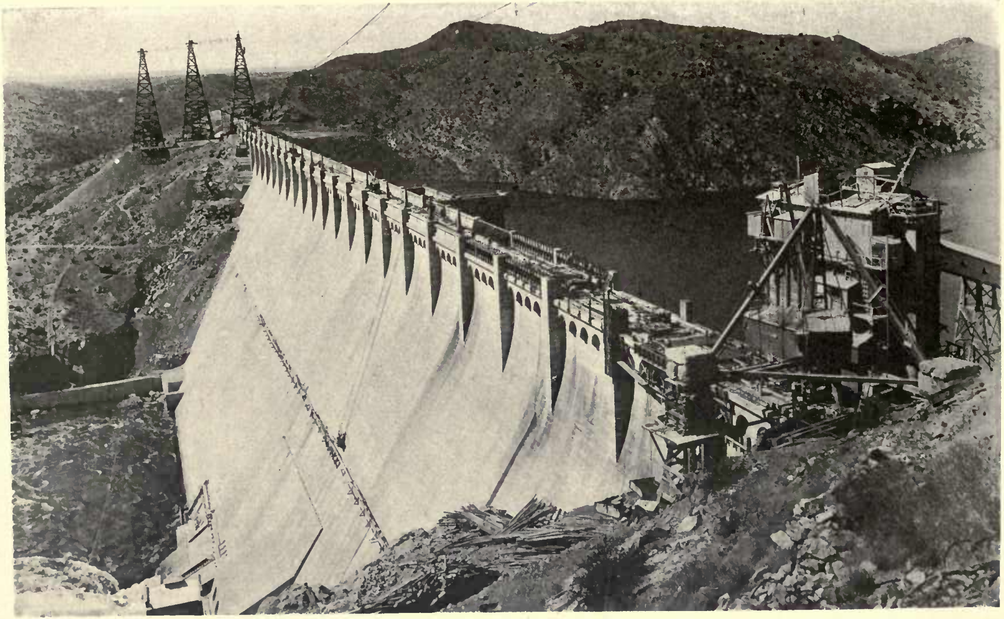


Fig. 82.—Elephant Butte Dam, Cableways and Mixing Plant, Rio Grande, New Mexico.

it had a bell-shaped mouth, and the estimated capacity was 16,000 cubic feet per second. The inner slope of the concrete flume was provided with several heavy grooves or corrugations which were later filled with lean concrete, producing a smooth surface but easily removable to restore the grooves to improve the bond with the mass concrete of the dam when the flume was incorporated with it. Into this flume the river was diverted by an earthen cofferdam.

The excavation of sand and gravel from the river-bed was made with large grab buckets and the material deposited in dump cars and hauled to a storage pile for use later in mixing concrete. A pit much wider than required for the dam was excavated for the purpose of using the sand and gravel therefrom in mixing concrete for the dam, there being no sand available, except in the river-bed. In widening the pit for this purpose drag scrapers were used to pull the sand down to where the cables could pick it up. These scrapers were drawn back and forth on endless cables operated by electric drum hoists.

Experiments extending over several years were made to determine the safety and feasibility of manufacturing sand-cement at Elephant Butte for use in the dam, and it was demonstrated that this would effect a saving of over $200,000 in the cost of the dam without sacrificing anything in quality or durability. The plant for manufacturing this sand-cement consisted of a gyratory crusher, a rotary dryer, a ball mill, an automatic mixing machine, and four tube mills, besides the necessary elevating and conveying machinery. The automatic mixing machine mixed the product of the ball mill with an equal quantity of Portland cement, which mixture was then ground in the tube mills to a fineness of 90 to 93 per cent, passing a No. 200 sieve. The finished product was carried by a belt conveyor to a large bin above the concrete mixing plant. The cost of the sand-cement plant was $56,000 and its capacity about 70 barrels per hour.

The concrete mixing plant was carefully planned to secure large capacity with the minimum amount of human labor. Two No. 7½ gyratory crushers were installed on the side hill about 20 feet lower than the railroad track on which the rock was hauled, and an entire train-load of rock could be dumped into the hoppers at one time. The crushed rock was elevated to the top of the tower containing the concrete mixing plant. There

the product of the crushers was passed through a drum screen, the fine material passing into the sand bin and the coarse into the rock bin. The sand and gravel from the river-bed was likewise screened and passed to the proper bins. Another bin alongside these two received the cement from the sand-cement mill.

Under these three bins were installed three concrete mixers, each with a capacity of 80 cubic feet. Above each mixer was located three measuring hoppers holding enough cement, sand, and stone for one batch of concrete. The contents of the mixers were dumped into hoppers capable of holding three batches each, so that the mixing could proceed regularly regardless of irregularity of delivery. From the hoppers the concrete was drawn into skips borne upon cars which ran on tracks leading under all the cableways so that any skip could be delivered to any cableway, which carried the concrete to place on the dam. Eight stiff-leg derricks of 8-ton capacity each were used on the dam to place the concrete and the rock. The total cost of the mixing plant, including storage bins, elevators, and haulage system, but excluding the rock crushers, was $57,800.

During the year ending February 28, 1915, 380,200 cubic yards of masonry was placed in the dam. The best day's run was 2,651 yards, on January 25, 1915, in 16 hours.

Cost of Manufacturing Sand-Cement, Elephant Butte Dam

Item	Total to January 1, 1916	Unit Cost
Supervision	$ 5,950.12	$0.009
Laboratory expense	9,078.87	.015
Portland cement	629,650.66	1.027
Sand or crushed rock	67,440.62	.110
Drying	2,613.45	.004
Pulverizing and grinding	31,365.55	.051
Sacking and handling	1,354.19	.002
Power, fuel and water	124,083.59	.202
Maintenance and repairs	25,271.12	.041
Plant, arbitrary	69,358.80	.113
Project, general expense	769.10	.001
Credit (by distribution)	$966,936.07	$1.575

The maximum output for any month was 40,205 barrels of sand-cement at a unit cost of $1.494 per barrel, in March, 1915. The minimum cost, however, was attained in the previous year,

with an output of 19,764 barrels, in February, at $1.425 per barrel. This figure was closely approximated in March, 1914, and January, 1915. The minimum output for any month was 1,433 barrels in December, 1913, at a cost of $2.672 per barrel.

The sand-cement plant discontinued operations on January 22, 1916, having manufactured a total of 622,551 barrels. Work of dismantling was started immediately.

COST OF ELEPHANT BUTTE DAM

Surveys, borings, etc.				$399,626
Excavation				699,248
Preparing abutments				384
Concrete, 605,200 yds. @ 5.35				3,237,411
Cement	518,236 yds.	@ 2.122,	$1,099,514	
Sand	518,236 "	" .147,	76,039	
Stone	518,236 "	" 1.407,	729,337	
Mixing	518,236 "	" .173,	89,494	
Placing	518,236 "	" .409,	212,006	
Large stone in place	86,964 "	" 2.763,	240,183	
Forms (wood)	605,200 "	" .297,	179,626	
Reinforcement in place			11,018	
Pumping and drainage			19,981	
Sprinkling			7,187	
Field engineering			28,869	
Maintenance of equipment			92,132	
Plant arbitrary			347,773	
General expense			104,252	
Grouting, cement gun, and bed-rock				30,883
Controlling machinery				205,997
Drainage wells				14,845
Embankment				129,946
Spillway				124,458
Excavation			$54,962	
Concrete			60,942	
Grouting			1,351	
Machinery			5,358	
General expense			1,845	
Transmission lines				1,267
Roads and bridges				26,656
Admin. General Expense				61,143
Total				$4,931,864

MESILLA DIVERSION DAM

A low diversion weir, 303 feet between abutments, with movable crest, has been constructed on the Rio Grande southwest of Las Cruces. It is of concrete with an ogee crest standing 2 feet above a reinforced concrete apron which covers the river-bed for a distance of 18½ feet up-stream from the weir. This apron is 9 inches thick where it joins the weir, and 6 inches thick at the upper edge, with a curtain 2 feet deep. The mass of concrete under the weir extends to a depth below the lip of the weir of 11 feet and 10 inches, narrowing to a thickness of 18 inches at the bottom. A concrete apron is provided below the weir to receive the falling water, extending to a line 24 feet down-stream from the weir-crest, and diminishing in thickness from 4 feet to 18 inches. A curtain wall extends 5 feet below the floor of the apron, and is provided with weep-holes to prevent the accumulation of pressure. This curtain wall is 18 inches thick at top and 12 inches at bottom.

A movable crest, 4½ feet high, surmounts the weir, in the form of a series of nine radial or "Tainter" gates, to be raised in time of flood to prevent inundation of adjacent lands. These gates have radial arms of 19 feet 4½ inches.

A steel bridge surmounts the entire structure and from this the radial gates are operated by means of wire ropes upon drums operated by hand or by power furnished by an eight horse-power gasoline engine, carried from one gate to another on a car.

A canal heads on each side of the river at this dam, that on the right bank having a capacity of 430 cubic feet per second, and its entrance is controlled by eight cast-iron gates of 4′4″ clear opening and 3′9″ high. The canal on the left bank has a capacity of 300 cubic feet per second and six head-gates of the same dimensions as those opposite.

The canal gates are at right angles to the dam.

A sluiceway 45 feet wide, to clear the gate entrances of mud, is provided at each end of the dam, each controlled by two "Tainter" gates 5½ feet high, with sills 1 foot below the crest of the main weir.

FRANKLIN CANAL

A diversion dam of masonry was built many years ago across the Rio Grande at the upper edge of the city of El Paso, one end

of the dam being within the city limits and the other end on Mexican soil. This dam has been repaired by the Reclamation Service, and the canal heading at this point has been enlarged and new head-works provided. This is called the Franklin Canal

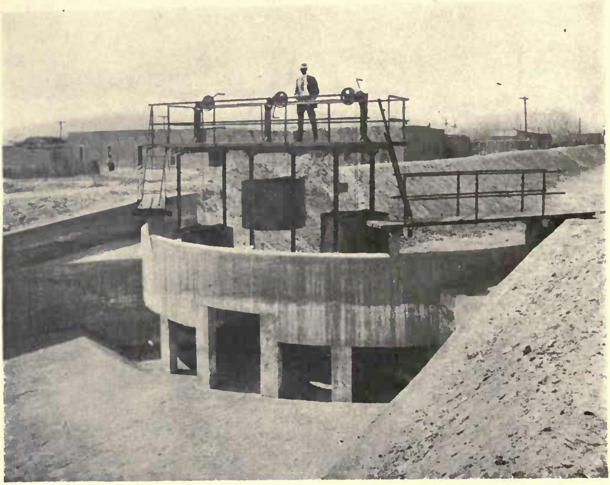


FIG. 83.—Cylinder Drop on Franklin Canal.

and covers the major portion of the lands to be irrigated in the El Paso Valley of Texas.

It follows about two miles through the city limits of El Paso, and in this distance has a deep, narrow section lined with concrete, with concrete structures, and has a capacity of 450 cubic feet per second. The upper 1,000 feet has a wider and deeper section, giving a capacity of about 1,000 cubic feet per second, and is lined with concrete, to be used for sluicing purposes. The larger section insures a low velocity through this reach, and the heavier materials taken in by the river are deposited here. By opening a gate at the lower end of the sluicing section and spilling the water back into the river, a high velocity is obtained, which scours out the deposited materials.

The canal following parallel to the river has a heavier grade

than necessary, which is absorbed in occasional drops as required. A novel design has been adopted for these drops, consisting of controlling balanced cylinder gates which can be adjusted to such discharge as will produce the proper velocity to prevent scour and deposit at all stages.

The Elephant Butte Dam was designed under the direction of Louis C. Hill. The dam and most of the canal system was built under the direction of E. H. Baldwin, although various portions were built under W. M. Reed, and later L. M. Lawson. The author is more directly responsible for the conception and general plan of this than any other project.

CHAPTER XVI

UMATILLA PROJECT

DESCRIPTION

The Umatilla River is a tributary of the Columbia and drains an area of about 2,000 square miles. It has a mean annual run-off of over 500,000 acre-feet, a large part of which is diverted by numerous canals and ditches and used for irrigation by private enterprise. The habits of flow of the stream, however, provide the major portion of the run-off in the winter and spring, and very little in the latter part of the growing season. No attempt had been made to store water prior to the irrigation operations of the Government in this basin and, in consequence, most of the canals of the valley were short of water in the summer and autumn.

This basin was first examined by the Reclamation Service in 1903, but no feasible storage site was found on the main stream or its tributaries. A basin in the sand hills west of the river, called the Juniper Reservoir site, was examined with a view to its being filled by a feed canal from the river, but the examinations developed such an extensive and porous substratum of coarse sand and gravel under the reservoir and feed canal as to make its probable losses fatal to the success of this project.

Further explorations and surveys developed a more promising site at Cold Springs, in a dry ravine east of the Umatilla, which could be filled by a feed canal from that river.

This project was recommended for construction in 1905, and construction began in 1906. The plan of reclamation involved the construction of a diversion dam on the Umatilla River, a feed canal to conduct water from the diversion dam to Cold Springs Reservoir formed by a dam in Cold Springs Canyon to store the flood waters of the Umatilla River, and a distribution system for conducting water from the reservoir to the irrigable land. For purposes of description, the work naturally

divides into three main features, the feed canal, Cold Springs Dam, and distribution.

STORAGE FEED CANAL

The feed canal has a maximum rated capacity of 300 second-feet. It heads on the Umatilla River, two miles above Echo,

Fig. 84.—Lined Portion of Feed Canal, Umatilla, Project.

Oregon, where a diversion dam and head-works have been constructed. The diversion dam is provided with a concrete overflow weir 400 feet long and 4 feet high, founded on a timber crib 3 feet deep and 23 feet wide, filled with rock, forming an apron upon which the overflow falls. Sheet piling is driven at the upper and lower edges of the crib. The foundations are all on loose gravel. The top of east abutment and head-gate structure are 7 feet above the crest of the weir. The west, or left abutment, stands 8 feet above the crest of the weir and joins an earth and gravel dike that extends about 2,000 feet to high ground, and is riprapped on the upper side. There are eight

cast-iron head-gates, each 21″ × 6′3″, with sills two feet below the crest of the weir. They are separated by reinforced concrete piers, and these piers are connected by curtain walls above the gates, so that no water can flow over the gates.

One thousand three hundred feet below the head-gates a structure is provided with gates across the canal similar to the head-gates and sluice-gates in the side of the canal, by opening which, and closing the check-gates, the water can be turned into the river at a high velocity and the gravel sluiced out of the head of the canal. Here the amount of water to be carried down the canal is regulated.

A considerable portion of the feed canal is lined with concrete for safety and for economy of excavation and of water. Most of this lining is 4 inches thick, but a part is 2 inches.

About half a mile before the feed canal reaches the reservoir, a by-pass chute is provided, by which water can be dropped down the hill into the distribution canal system about 17 feet lower. This is a concrete chute of trapezoidal section with a stilling basin at the bottom.

At the discharge of the canal into the reservoir a large concrete drop is built to prevent back-cutting along the canal. A short distance above its outlet, the canal is provided with a set of gates in the form of flap valves which remain open as long as the water is flowing toward the reservoir, but close when a current starts in the opposite direction. This prevents back-flow when the reservoir is full and the feed canal supply is stopped.

COLD SPRINGS DAM

This dam is built of earth, sand, and gravel. It has a height of 100 feet, a top width of 20 feet, and slopes of 3 to 1 on the water slope, and 2 to 1 on the down-stream slope. It forms a reservoir in Cold Springs Canyon of about 50,000 acre-feet capacity, filled by the feed canal from Umatilla River.

The outlet conduit is located on bed-rock a little south of the center of the canyon, about 17 feet above the bottom of the canyon. The outflow is controlled from a tower built in the reservoir upon bed-rock at the upper end of the conduit, and reached from a bridge extending from the top of the dam. In this tower are installed two cast-iron sluice-gates, each 4 feet square, placed in

series, one at the outside of the gate-tower and the other at the inside, the former being an emergency gate, and the latter used in ordinary service.

The outlet conduit is built of reinforced concrete and is of horseshoe cross-section, 6 feet wide and 5 feet high, with cut-off collars at intervals of 30 feet. It discharges into a canal cut in rock which has a capacity of 225 cubic feet per second.

A spillway is provided on the right bank just above the dam. Its concrete overflow lip is 330 feet in length and is 8 feet lower than the crest of the dam. After spilling over the crest, the water glides down a 2 to 1 concrete slope into a concrete-lined channel nearly parallel to the spillway lip and at right angles to the dam, becoming larger and deeper until it discharges into the canyon below the dam. Although this channel terminates in rock, it is provided with a heavy curtain wall to prevent erosion. The concrete lining of the spillway channel is constructed in blocks 10 feet square with joints underlaid with cut-off walls of concrete. Where it is founded upon sand, it is reinforced and provided with weep-holes on the slope nearest the dam. With a head of 3 feet, this spillway will discharge about 5,900 second-feet, leaving 5 feet freeboard on the dam; this with the storage of 3 feet on the surface of the reservoir will take care of the largest flood known, with a good margin to spare.

The foundation and left abutment of the dam are of sandy earth, while the right abutment is volcanic rock. A cut-off trench was excavated to depths varying from 6 to 20 feet, under the upper toe of the dam, and this trench was filled with good material well puddled and rolled in place. A series of eight concrete wing-walls, 1 foot in thickness at the top, form the bond between the right abutment and the dam. One of the accompanying illustrations shows this dam under construction, indicating the methods of transporting, spreading, mixing, sprinkling and rolling the materials. The concrete cut-off walls joining the end of the earth bank to the right abutment are also shown in this view.

An extensive bed of fine gravel occurs on the side of the canyon below the dam, and this was the principal material of construction. The gravel contains considerable coarse sand, but is so open that it would not alone form a water-tight structure.

Accordingly, the gravel in the body of the dam for one-third its thickness nearest the water slope is mixed with an equal volume of loam obtained in the vicinity and the middle third is one-fourth loam and three-fourths gravel. The down-stream third is composed of the run of the gravel bank, which is nearly pure gravel and coarse sand. The water slope of the dam is covered with 1 foot of gravel, and both slopes blanketed with rock as it comes from the quarry, being jagged, irregular stones from 10 to 100 pounds in weight pitched to a thickness of 2 feet on the inner and 1 foot on the outer slope.

The face of the gravel bank was from 20 to 50 feet in height overlaid with loam from 2 to 10 feet in depth. Where the loam layer exceeded 8 feet in depth it was loosened in advance by powder. The gravel, clean or mixed with loam, was loaded in 4-yard dump cars by a 70-ton steam shovel with a 2½-yard dipper. The average length of gravel haul is about 2.3 miles, with a considerable proportion of up-grade on a slope of 1¼ per cent, the total rise from the gravel bank to the summit of the track being 65 feet. There was one switchback on this track, entailing the corresponding delay to each train-load. Four trains, consisting each of one locomotive and ten 4-yard dump cars, were employed to transport this material, yet frequently the shovel had to wait for cars.

In the beginning of construction a trestle 65 feet in height was built across the canyon, and the gravel was dumped from that until the dam reached the height of the trestle, when the track was laid on the down-stream edge of the bank and raised and drawn in as the work progressed. The gravel was removed and spread by means of four-horse fresno scrapers, of which eight were employed for this purpose. Two men and a dump cart were employed removing boulders occurring in the gravel, which were dumped on the face for riprap.

The output of the shovel occasionally reached a maximum of about 2,300 yards in a day of eight hours, and the average was about 1,600 yards, or 200 yards per hour. The cost of the principal equipment delivered on the work and ready for operation used in handling gravel is as shown in Table 1, page 260.

The total depreciation on the equipment has been figured at $54,280. The total amount of gravel required is estimated at

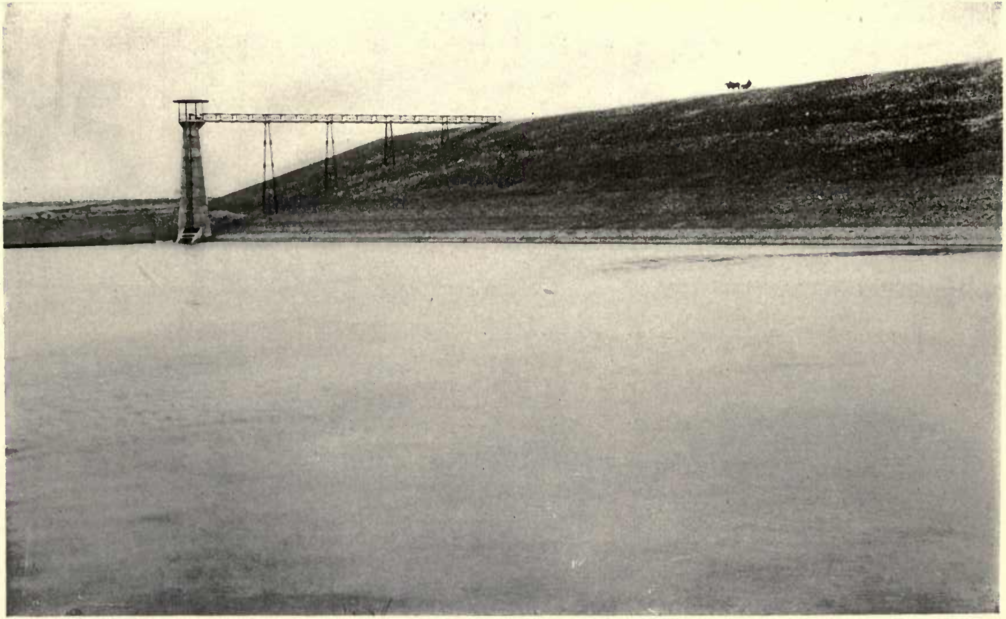


FIG. 85.—Cold Springs Dam and Outlet Tower, Umatilla Project, Oregon.

590,000 cubic yards, making the cost of depreciation of plant per cubic yard moved, 9.2 cents.

TABLE 1.—COST OF PRINCIPAL EQUIPMENT, COLD SPRINGS DAM

Items	Cost	Depreciation
One steam shovel, 70-ton, 2½-yd	$14,147	$8,147
Four locomotives, 16-ton	15,121	7,051
Forty-five dump cars	13,872	9,012
Four miles 30-in. track, 35-lb. rails	25,187	20,447
Trestle	10,263	9,263
Sundries	....	270
Total	$78,590	$54,190

The loam was excavated chiefly by means of an orange peel excavator, by which it was loaded into dump wagons that hauled and placed it where needed to mix with the gravel. Where convenient, some of the loam was hauled in fresno scrapers, and in portions of the cut-off trench wheel scrapers were used. The loam was dumped in piles from the wagons, and spread by means of a road machine into a layer of 3 to 4 inches. Upon this the fresnoes spread an equal layer of gravel, after which these two layers were mixed by three 2-horse cultivators. Disk harrows were at first employed for this purpose but proved to be not efficient, so were discarded. After the cultivators had mixed the layer it was thoroughly wet with three lines of sprinkling hose, and then rolled with two 5-ton loose disk rollers, each drawn by six horses, and formed a compact layer of 6 inches. The cost of gravel embankment and of the earth embankment is given below:

TABLE 2.—COST OF GRAVEL EMBANKMENT AND OF EARTH EMBANKMENT, COLD SPRINGS DAM

Gravel Embankment	Cents
Excavating by steam shovel	3.5
Hauling, railroad maintenance, etc	7.0
Spreading and mixing	8.8
Sprinkling	1.0
Rolling	.5
Engineering, superintendence and general expense	5.7
Repairs	9.2
Total cost per cubic yard	35.7

TABLE 2.—*Continued.*

Earth Embankment	Cents
Loading and hauling	9.5
Spreading and mixing	3.8
Sprinkling	1.1
Rolling	.8
Depreciation	4.2
Repairs	.3
Engineering, superintendence, and general expenses	3.7
Total cost per cubic yard	23.4

As the dam is approximately one-fourth loam and three-fourths gravel, the combined cost was about 33 cents per cubic yard, measured in excavation. The thorough mixing and compacting caused a shrinkage of about 16 per cent, making the cost in embankment about 39 cents.

Advertisement called out two bids, the lowest of which was 31 cents for earth and 45 cents for gravel, or a combined rate of 41.5 cents. Omitting the items of engineering and general expenses which would have been incurred by the United States had the work been done by contract, the cost by Government forces was about 30 cents.

The Cold Springs Dam and the project of which it is a part were planned by Mr. D. C. Henny, supervising engineer, and Mr. E. G. Hopson, assistant supervising engineer, Pacific Division, in consultation with Mr. A. J. Wiley. Mr. J. T. Whistler was engineer in charge of the project and the dam was built under the immediate superintendence of Mr. B. H. Davis.

DISTRIBUTION SYSTEM

The distribution system of the Umatilla Project is extremely complicated on account of the character of the topography and sandy soil. Many pressure pipes were necessary to reach isolated tracts or to cross depressions, and the open sandy soil required the lining of many canals and laterals to avoid excessive seepage losses. Many drops and chutes were also necessary to deliver water safely from higher to lower levels. Experiment developed methods of manufacture and construction for reinforced concrete pipe that have proved of value and interest wherever such work is required.

The pipe mostly employed was made of concrete of one part cement, 2.3 parts sand, and three parts gravel. The sand was

clean and of medium grain. The gravel all passed a screen of 1-inch mesh and was held on a screen of ¼-inch mesh.

The reinforcement used was $\frac{5}{16}$-inch mild-steel wire wound on a drum into a helical coil. The spacing of the reinforcement was varied roughly according to the head to be sustained, so that the maximum stress should not exceed 12,000 pounds per square inch. The pipe was cast in lengths of 8 feet in steel forms. The outer forms were segmental, three segments making a circumference, the segments being 2 feet high. They were of ⅛-inch steel plate stiffened by $2'' \times 3'' \times \frac{3}{16}''$ angles. The inner form or core consisted of a cylinder 8 feet in length, formed of ¼-inch steel plate with hinges to permit its collapse and a key piece to hold it in shape while in use. The inside diameter of the finished pipe was 46 inches, and pipe of this size was given a thickness of 2½ inches. Cast-iron rings were placed upon the ground to serve as end molds to the joint of pipe. The pipes were all manufactured on end in a yard where all materials were handy and conditions favorable and were hauled to the point of installation after being cured. In some cases the pipes were laid end to end in the trench and the joints sealed by pouring concrete within special form collars, casting a concrete collar on each joint 4 inches wide and 3 inches thick, reinforced by two wires of $\frac{5}{16}$-inch mill steel hooked together at the ends. In other cases the collars were cast in the yard and sealed on with mortar in the field. Both methods gave good results. See Figs. 45 and 46.

Following are listed some of the pressure pipes used on the eastern division of the Umatilla Project, with cost of making and laying:

Line	Year	Diameter, Inches	Maximum Head, Feet	Length, Feet	Cost	
					Total	Per Foot
M	1907	47	55	4,680	$28,747	$6.14
D2	1907	30	22	1,724	4,618	2.67
D3	1907	30	35	1,395	4,876	3.51
O1	1908	46	36	5,312	23,942	4.50
R2	1908	46	15	1,284	5,184	4.04
O2	1908	30	26	3,556	10,400	2.93
R3	1908	30	25	3,645	8,864	2.43
B	1909	30	55	392	3,954	4.24
R1	1909	46	110	9,831	50,805	5.17
R4	1910	30	18	1,622	3,736	2.30
D1	1910	30	45	5,330	14,343	2.69

Generally, pipe designed for 25-foot head or more was given one or more coats of cement grout, which decreases percolation. The above cost given for the pipe on line M, which was the first built, includes the cost of all preliminary and experimental work, which accounts for the apparent high cost.

The distribution of the costs among the detail operations for two representative lines is given below, one being 30-inch pipe and the other 46-inch. In the case of the 30-inch, it is the longest line laid of that size, and in the case of the 46-inch, both the longest line and the highest head of that size:

Item	Cost per Linear Foot	
	R1—46″	D1—30″
Engineering	$0.048	$0.018
Labor: Clearing sage-brush from line	.006	.000
Excavating trench	.238	.230
Backfilling and protecting line with brush	.192	.200
Hauling pipe from pipe yard	.296	.152
Laying pipe and making joints	.388	.277
Tests on experimental sections	.034	.....
Painting pipe with cement grout	.043	.....
Priming pipe	.002	.....
Miscellaneous labor and hauling	.089	.042
Manufacturing pipe	2.905	1.251
Cost of cement	.069	.048
Steel and miscellaneous supplies	.080	.018
Castings, valves, and manholes	.037	.018
General expense	.741	.436
Total	$5.168	$2.690

The new canals on the Umatilla Project showed large losses from seepage owing to the open character of the soil. In fact, in the first two years of operation less than half the water drawn from the reservoir ever reached the farms, and the loss upon the farms was likewise large. Many of the canals improved with use and some became fairly tight by settlement and some silting. The fact that most of the water was drawn from the reservoir, and was consequently clear, prevented much benefit from silting, and it was early decided that many of the worst canals and laterals must be lined with concrete in order to reduce the waste of water stored at great expense, and also in order to reduce the damage to lower lands which were being waterlogged by the excessive seepage.

About 7,000 linear feet of 16-inch and 11,000 linear feet of 12-inch pipe were used in the system either as pipe drops or as pressure pipe under low heads. They were mixed rather dry and with great care and generally without reinforcement. For heads over 15 feet the pipe was reinforced with No. 10 wire. The average cost of 16-inch pipe was 30 cents per foot and of 12-inch pipe 20 cents per foot.

FIG. 86.—Drop from Main Canal, Umatilla Project, Oregon.

All of the pipe used on the project has given satisfactory service, no failures and no serious leaks having occurred.

The large losses of water from canals and laterals and the large quantity escaping into the subsoil on the farms brought up the ground water table on the lower lands, and soon bogs and ponds began to appear and gradually to enlarge. This condition was aggravated by the absence of natural drainage lines and the existence of isolated depressions characteristic of a topography formed by wind. In fact, but little of the lost water was able to reach the river except through the subsoil. To correct the seepage and prevent its spread, about 10 miles of open drainage channels were excavated and 8,350 feet of underground tile drains

were constructed. The drainage from the project into the Umatilla River exceeds 100 cubic feet per second in the summer, and forms the major portion of the water supply available for diversion to irrigate the west extension of the project.

WEST EXTENSION

The west extension of the Umatilla Project takes water from the river on the left bank below all other important diversions to irrigate lands in the Columbia Valley near Irrigon and westward. The water supply consists mainly of the return seepage, drainage, and waste water from the lands on the various projects irrigated above, and is deemed ample for the irrigation of about 10,000 acres of land. A basin occurs in the valley among the irrigable lands, which can readily be closed by embankments to form a reservoir that could receive water from the main canal and extend the acreage by several thousand acres. The open, sandy character of the subsoil suggests doubt as to its capacity for retaining water, but it can be tried at small expense by means of low embankments before any large investment is made. A reservoir has also been examined to store water between Stanfield and Hermiston, but its feasibility is in doubt, mainly on account of the great expense involved in the long, heavy embankment and the large land damages to be paid, and also the open character of the coarse, sandy hills that form the abutments of the proposed dam.

THREE-MILE FALLS DIVERSION DAM

This dam is located about half-way between Hermiston and Umatilla on the Umatilla River. It is built of concrete of a multiple arch design, the axis being curved to a radius of 1,200 feet. There are forty arches resting against buttresses which are 20 feet center to center. The arches are 1 foot thick at the crest and increase in thickness downward at the rate of 1½ inch for every foot vertically. The outer face of each arch is curved to a radius of 18 feet, and the inner face to a radius varying from 16 to 17 feet, according to thickness. The maximum height of the dam above the river-bed is about 24 feet. The up-stream face of the arches is inclined to a slope of 1¼ to 1, and the down-stream edges of the buttresses have a batter of 1 in 12. A back

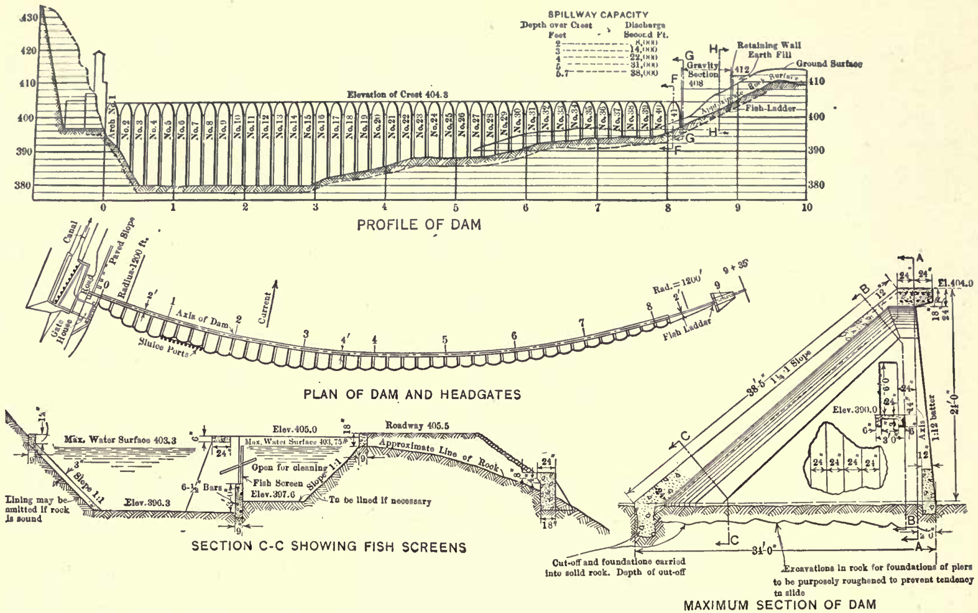


Fig. 87.—Elevation, Plan, and Section, Three Miles Falls Dam, Umatilla River, Oregon.

wall traverses the entire length of the dam except a distance of 180 feet in the river section. This wall averages 4 feet high and 1 foot thick, and is reinforced longitudinally with six half-inch rods, fastened securely at their intersections with the steel in the piers.

At the up-stream toe of the dam is a heavy cut-off wall, 6 feet thick and from 6 to 10 feet deep.

The buttresses are 18 inches thick and are reinforced with two parallel vertical tiers of ½-inch steel spaced 2 feet apart. The crest of the dam is 4 feet wide and spans the space between buttresses as an arch of 16-foot radius, heavily reinforced by ½-inch rods spaced 6 inches apart each way. An inspection gallery runs the length of the higher part of the dam, and greatly stiffens it. The floor of this gallery is 3 inches thick and is supported by a floor-beam on each edge, 6 inches thick and 11 inches deep, and reinforced with two ½-inch rods wired at the ends with the steel in the buttresses. Openings occur in the buttresses to allow the gallery to extend through.

Under arches 6, 7, and 8, counting from the west abutment, are located nine sluice openings, three under each arch. Each opening is 4 feet wide by 2½ feet high, and is provided with flash-board grooves, 10 inches wide and 4 inches deep. These sluices were provided to pass the running stream during construction. They were closed after the completion of the dam by dropping reinforced concrete slabs down the grooves.

The head-works of the canal are located on the left bank of the river at the west abutment of the dam and are at right angles to the axis of the dam. There are three gate openings, each 5 feet wide and 6 feet high, operated in a 12×20 concrete gate-house. Just below the gate-house a concrete highway bridge spans the canal. Just below the bridge are ten revolving fish screens, installed between piers.

The sandy soil and coarse subsoil of the lands of the west extension, together with the experience with similar conditions on the eastern division of the project, led to a decision that the entire canal and distribution system of the west extension should consist of concrete channels. The lining of canals and the manufacture and installation of concrete pipe therefore become even more important than on the eastern division.

To reduce the amount of lining, save head and provide the

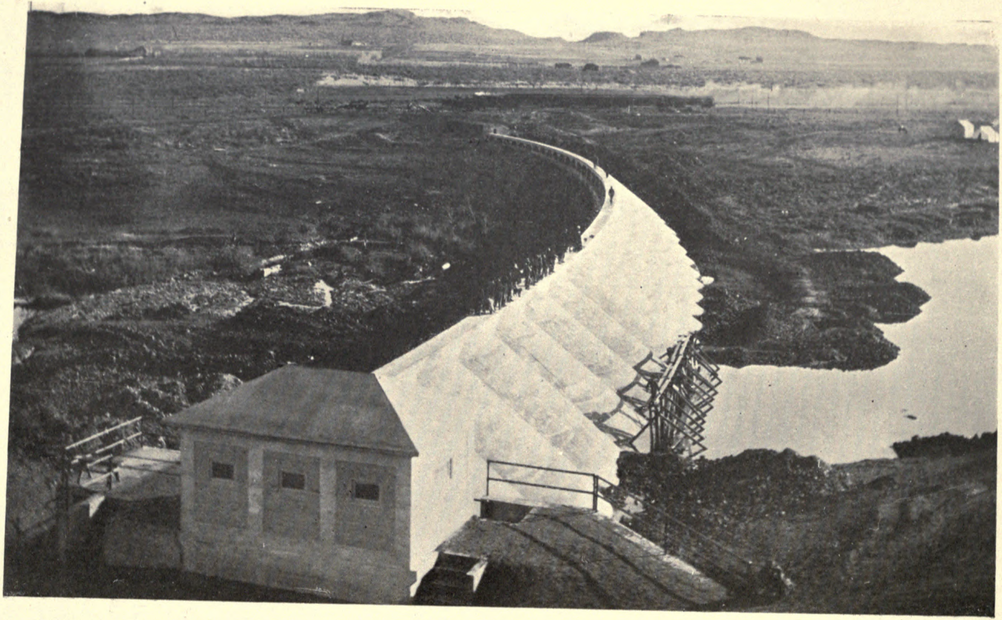


Fig. 88.—Three Miles Falls Dam.

necessary velocities for cleansing purposes, the section chosen for canals was deep and narrow. The side slopes were 1½ to 1, and the bottom on a curved invert as shown in the drawing. The main canal at its head has a capacity of 360 cubic feet per second, a total depth of 9½ feet, a maximum water depth of 7 feet, leaving 2 feet freeboard on the bank. The concrete lining is 3 inches thick, and extends 6 inches vertically higher than the normal water level of the full canal. The lower bank has a top width of 12 feet in order to serve as a roadway. The lining for the main canal was 3 inches thick, and was mixed by machine in the proportions 1 : 3.5 : 5.2.

The gravel all passed a 2-inch screen and was held on a ⅜-inch. Experience indicates that less smoothing would have been required with smaller gravel. The theoretical yardage of concrete required per linear foot was .285, but .325 was actually required, due to imperfect finishing and losses, an increase of about 14 per cent; 1.04 barrel of cement was used per cubic yard, and the total cost per cubic yard was $8.16.

The Umatilla Project is in charge of H. D. Newell, under whom the West Extension is being built.

CHAPTER XVII

KLAMATH PROJECT

DESCRIPTION

The topography of the Klamath Project is characterized by a rather complicated system of lakes and rivers with somewhat curious relations to each other.

Upper Klamath Lake is a large, fresh-water lake discharging its surplus through the Klamath River to the Pacific. Lower Klamath Lake has a very small drainage directly tributary to it but is connected naturally with the Klamath River by a narrow slough. During the season of high water this slough carries water from Klamath River to the lake, and when the freshets have passed and the level of the river declines, the current of the slough is reversed and it carries water from the lake to the river. Thus the stage of the lake follows tardily that of the river.

Clear Lake bears a similar relation to Lost River and its upper feeder, Willow Creek. When the latter was in freshet it overflowed into Clear Lake, which discharged its surplus water through Lost River. Lost River follows a circuitous course and discharges into Tule Lake, which has no visible outlet, but disposes of its water by evaporation and seepage. It normally covers an area of about 90,000 acres, which fluctuates with the varying discharges of different years and cycles of years.

MAIN CANAL

The main irrigation canal of the Klamath Project heads in Upper Klamath Lake. The head-works at the lake consist of six steel gates set in concrete, each 5 feet wide and 8 feet high, separated by piers 2 feet thick, with grooves for flash-boards so that the gates can be unwatered for examination or repair. The capacity at low water is about 1,000 cubic feet per second. (See 5th Annual Report, page 258.)

The canal for about 2,700 feet is in deep cut 13½ feet in bottom width, with side slopes about ½ to 1 and lined with concrete

6 inches thick. At the end of this cut the water enters a tunnel of the same width, rectangular except for an arched top, and also l ned with concrete.

About 9 miles below the head-works a large lateral, known as the South Branch Canal, branches to the southward while the main canal continues, in a general easterly course, to the lower end of Poe Valley, where it sends a lateral eastward to irrigate the north side of Poe Valley, and crosses Lost River in a flume, after which it branches to the east and west, to water lands on the south side of Lost River, those to the east being in Poe Valley and those in the west including a strip of land parallel to Lost River, reaching to the northern end of Tule Lake.

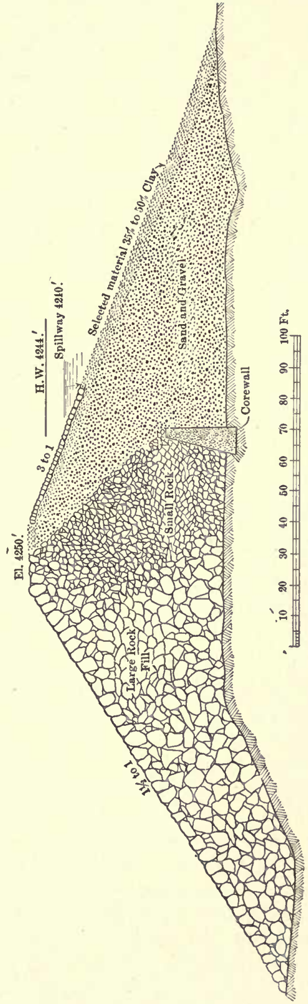


FIG. 89.—Section of Clear Lake Rockfill Dam, Klamath Project.

CLEAR LAKE RESERVOIR

Lost River is the main source of water supply to Tule Lake, from which it is all lost by evaporation and seepage, there being no visible outlet. The plan of the reclamation project involves the un-

watering of a portion of the lake bed, and its irrigation afterward. To exclude from the lake so far as possible the waters of Lost River, a regulating reservoir is provided at Clear Lake, and the regulated waters are diverted by a dam near Wilson's Bridge into a channel with a capacity of 350 cubic feet per second, and carried thereby to Klamath River. In this way, only the flood waters of Lost River, exceeding the above capacity are allowed to reach Tule Lake.

The storage dam at Clear Lake is a combination of earth and rock-fill and is 33 feet high. This dam has a core-wall only at the base. The rock-fill grades from coarse to fine toward the earth-fill, which serves to produce water-tightness and is protected from wave action by a rough pavement of rock. The lower or loose rock slope has an inclination of about 1½ to 1. The area of the reservoir formed is about 25,000 acres, and has so far disposed of all surplus water by evaporation and seepage, and this supply is thereby entirely eliminated from Tule Lake.

LOST RIVER DIVERSION DAM

The diversion dam near Wilson's Bridge is of unique design, as shown in the drawing, Fig. 90. It was necessary to raise the water nearly to the elevation of the flood plain in order to make the diversion channel feasible. On the other hand, the water must not be permitted to much exceed the same level in flood times lest it overflow valuable lands in the valley above, which has a very flat gradient. It thus became necessary to provide a long overflow weir with movable crest, to afford the necessary discharge at the permissible head. To secure this, the dam was designed in plan to be of the shape of an elongated horseshoe with the toe up-stream. This causes the overflow to fall in the interior of the horsehoe, and thus to dissipate its surplus energy in opposing currents and whirlpools before leaving the solid concrete structure, which it leaves very placidly. A similar length of weir across the valley would have involved a large amount of excavation to carry the structure down to suitable foundation, besides requiring expensive provisions for conducting the overflow harmlessly to the natural channel below.

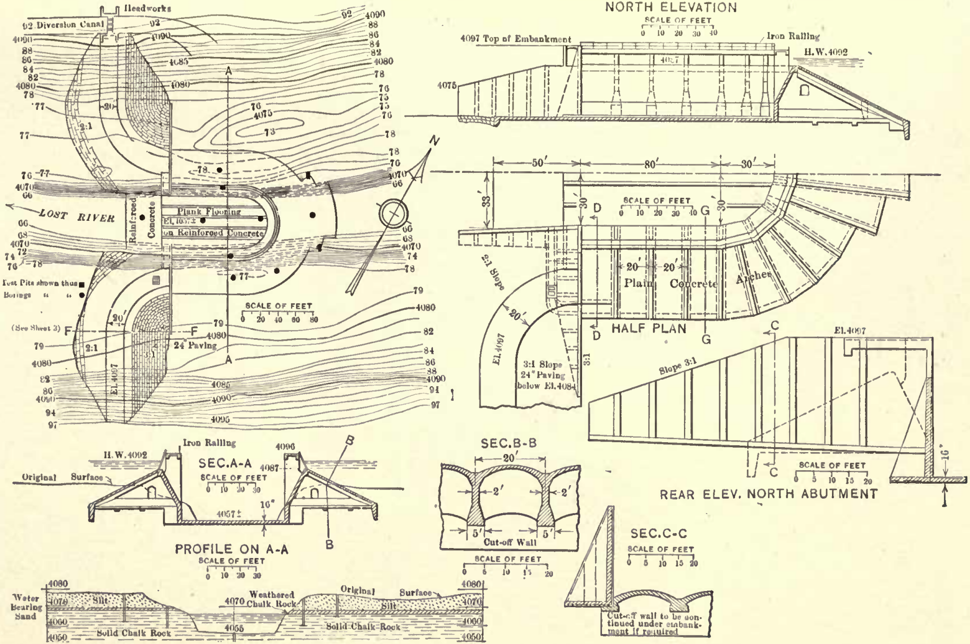


Fig. 90.—Diversion Works, Lost River, Oregon.

KENO POWER CANAL

When the Klamath Project was taken up, the low-water flow from Upper Klamath Lake was nearly all appropriated by a power development at the rapids just below the outlet. The needs of the project required that this right be extinguished at least to the extent of releasing enough water for the extensions

FIG. 91.—Lost River Diversion Dam, Klamath Project.

projected. This was accomplished by the construction of a power canal from the lake to a point 6,200 feet below, just opposite the town of Klamath Falls. At this point a drop of 50 feet is obtained, and a discharge of 200 cubic feet per second develops sufficient power to replace the old power right. The power canal, however, has a capacity of about 600 cubic feet per second, which leaves about 400 cubic feet for future use in power development. This is destined for use in pumping irrigation water to levels too high to be served by gravity, and for assisting in drainage operations.

The power canal has an overflow weir to dispose of surplus waters incident to the fluctuating demands of the power-plant.

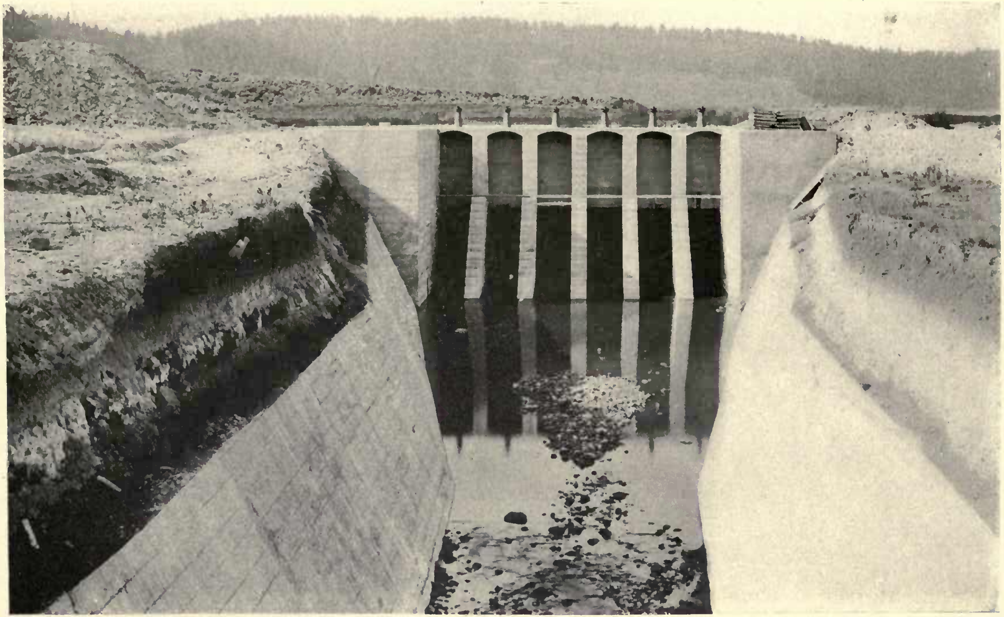


FIG. 92.—Head-works Main Canal, Klamath Project, Oregon.

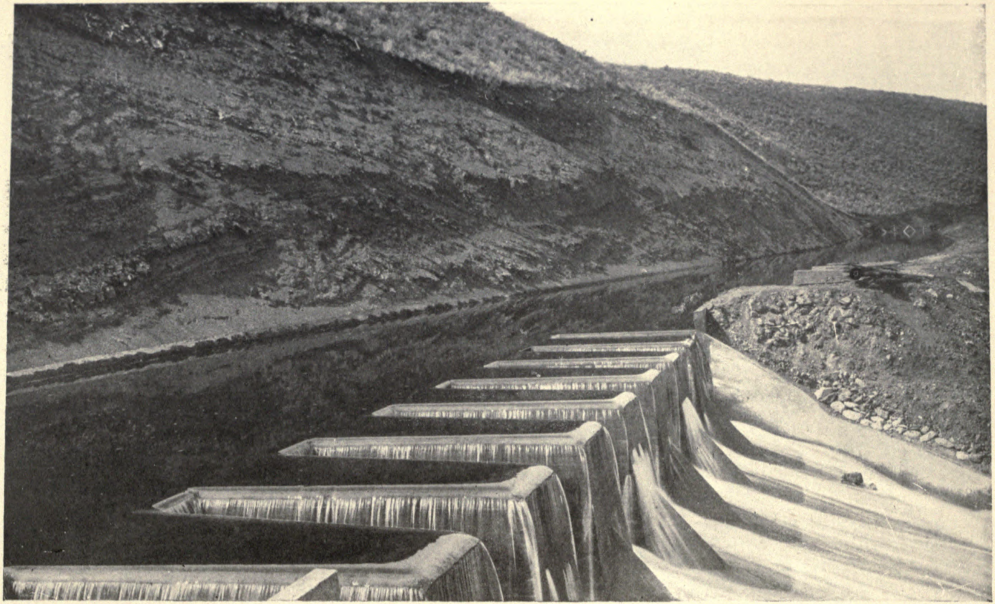


Fig. 93.—Keno Canal Spillway, Klamath Falls, Oregon.

The necessary length of overfall was obtained by building the weir in a series of rectangles, as shown in the illustration, Fig. 93.

KLAMATH MARSHES

One feature of the Klamath Project is the possible reclamation of the lower Klamath marshes and a portion of Lower Klamath Lake. This lake receives overflow water from Klamath River when that stream is high, and returns a portion to the river when low. The development of the project attracted a railroad to Klamath Falls, to reach which point a fill across the marsh was necessary.

Arrangements were made with the railroad company by which the United States assumed the responsibility of closing navigation between the river and lake, and in return the railroad company constructed a muck ditch under the dike and otherwise adapted it to serve as a levee to keep water out of the lake. A culvert was provided through this levee, with provision for controlling the flow of water in either direction.

The reclamation of the marshes, however, received a serious setback by the results of experiments which were made to test their fertility. A small area in the northwest part was diked off and unwatered by pumping. Drain ditches were provided to control the ground water, and crops were planted, but the results were so poor as to cast grave doubt upon the advisability of attempting reclamation, at least with hopes of securing anything better than pasture. The experiment of reclamation must, therefore, proceed with caution in order to avoid unproductive expenditures.

The earlier works of the Klamath Project were built under the direction of D. W. Murphy, who was succeeded by W. W. Patch, under whom the Lost River Dam and some other features were constructed. J. B. Lippincott, D. C. Henny, and E. G. Hopson were successively Supervising Engineers.

CHAPTER XVIII

BELLE FOURCHE PROJECT

DESCRIPTION

The Belle Fourche River drains an area of about 4,300 square miles in western South Dakota and eastern Wyoming, including the northern slope of the Black Hills. The discharge of the stream occurs mostly in the spring and early summer months, the river being relatively low in late summer and fall. Irrigation on a large scale, therefore, must depend upon storage for a full season's supply.

The Reclamation Project provides for the diversion of the river at a point a short distance below the mouth of the Red Water, into a feed canal which carries it to a storage reservoir provided on Owl Creek at its junction with Dry Creek, about seven miles from the diversion point. The irrigable land is situated on both sides of Belle Fourche River, about two-thirds being on the north side and one-third on the south.

DIVERSION DAM AND FEED CANAL

The diversion of the Belle Fourche River into the feed canal is accomplished by a dam having a total length of 1,300 feet, 400 feet of which is an ogee concrete overflow weir in the river section, and 900 feet is an earth embankment of 6,000 cubic yards, paved with rock on the water slope. The concrete weir is 25 feet high and contains 12,200 cubic yards. It is founded on shale, and its right abutment joins the earth embankment. The left abutment is a compound structure, comprising the head-works of the feed canal and the sluice-gates of the dam, designed to clear mud and débris from the entrance to the feed canal. There are three sluice-gates 4 × 7 feet, and seven gates to the canal head-works, each 4 × 6 feet. All the gates are cast iron with rising stems of bronze and ball-bearing gears operated by hand. The back of the dam is vertical, the top is curved on a 5-foot radius to thick-

ness of about 6 feet, and the front slope is ¾ to 1. The bed of the river below the dam is protected from the impact of the water for about 10 feet, with a 2-foot layer of concrete, and with riprap both on bottom and sides for a considerable distance farther. The dike on the right bank has a water slope of 3 to 1,

Fig. 94.—Head-gates, Belle Fourche Feed Canal.

protected with rock paving, a top width of 10 feet, and a downstream slope of 1½ to 1.

The grade of the feed canal is about 8 feet above low water in the river, and the depth is 10 feet. The bottom width is 40 feet, and the side slopes are 1½ to 1, except in thorough cuts, where they are 1 to 1. The banks stand 3 feet above the water-level, and have a top width of 8 feet.

The grade of the canal is .0002, and its capacity is about 1,600 second feet. It has a length of 6½ miles, and enters the reservoir basin through a 43-foot cut.

Its terminus is protected by a semicircular concrete weir, 180 feet long, founded on shale, with a maximum depth of 2 feet of water over its crest at full canal discharge.

Where the feed canal crosses Crow Creek, a concrete overflow weir 180 feet long is designed to discharge floods in Crow Creek, and in this weir are provided three sluice-gates, 5 × 10 feet each, with sills below the grade of the canal, to sluice out the mud washed in by Crow Creek.

BELLE FOURCHE RESERVOIR

The storage reservoir is formed by an earthen dam built across the valley of Owl Creek just below its junction with Dry Creek, about 10 miles northeast of the town of Belle Fourche. The reservoir capacity is shown in the following table:

CAPACITY OF BELLE FOURCHE RESERVOIR

Elevation, Feet above Sea-Level	Area, Acres	Section, Acre-Feet	Capacity, Acre-Feet Outlet
2,920	583	......	....
2,930	1,240	8,931	8,391
2,940	2,084	16,508	25,439
2,950	3,852	29,993	55,432
2,960	5,573	46,768	102,200
2,970	7,174	63,612	165,812
2,975	8,010	37,958	203,770*
2,980	8,888	42,246	246,016

*Spillway.

The dam is 6,493 feet long, has a maximum height of about 122 feet, and contains 1,634,000 cubic yards of earth. The water slope of the dam for a short distance above the toe is 5 to 1, this flat slope being near the bottom and unprotected against wave action. At the upper edge of this slope, 70 feet below the top of the dam, is an 8-foot berm, where a row of round piling is driven into the foundation, on 5-foot centers, the heads projecting above the slope and capped with concrete sufficiently to serve as a footing for the paving on the slope above. From this line up to the normal water level the slope is 2 to 1, and above that point to the top the slope is 1½ to 1. The top width is 18.6 feet.

The down-stream slope is 1⅔ to 1, to a line 30 feet below the top, where an 8-foot berm occurs, below which the slope is 2 to 1 to a similar berm 30 feet lower, and the clay is continued on a 2 to 1 slope to the base. A blanket of gravel is placed from the lower berm to the base, so as to widen the berm to 14 feet,

and flatten the slope to the base to 2½ to 1. On each berm a concrete gutter is placed to catch rain-water running down the slope and conduct it away from the dam.

The dam is provided with four rows of perforated pipes installed to show the level of water in the dam and thus indicate the lines of saturation. Observations taken on these pipes do not indicate any saturation of embankment.

CONSTRUCTION OF OWL CREEK DAM

The material on which the dam rests is a heavy compact clay, the surface residual of soft shale, into which the clay gradually merges at a depth of 20 to 40 feet below the surface. The dam is constructed entirely of this clay, of which nearly all the soil of the neighborhood consists.

A cut-off trench was excavated the entire length of the dam to a depth of from 5 to 20 feet, 10 feet wide on the bottom, with side slopes of 1 to 1. It was refilled with selected material in 4-inch layers, wetted and rolled. Additional trenches were provided in the wider portions of the base.

The clay of which the dam is built, like all clays in the arid West, contains some soluble salts, which are evidently not desirable in a bank required to resist percolation of water. Accordingly, samples were taken of the materials from various pits near the work, and were tested in the laboratory of the Geological Survey.

Sample No.	Per Cent Soluble Matter	Most Abundant Soluble Salt
3	1.68	The sulphate and carbonate (in solution the bicarbonate) of calcium were in each case the prevailing salts.
4	1.37	
6	2.92	
7	3.02	
12	1.96	
13	2.94	
15	2.85	
18	1.98	

Five grams of the powdered earth were introduced into a platinum dish and 500 cubic centimeters of cold distilled water added, the earth stirred for about seven hours, and the whole

left standing for twenty-four hours. The solution was then filtered and the remaining insoluble earth washed three times with about 300 cubic centimeters of cold, distilled water for each washing. The filtrate was then evaporated to dryness in a platinum dish, and heated to 180 degrees Centigrade to constant weight.

Localities represented by samples showing more than 2 per cent of soluble matter were rejected.

The clay was placed in the dam partly by steam-shovels and dump cars drawn by locomotives, and partly by elevating graders and dump wagons. The earth dumped from cars was first spread by fresno scrapers and levelled with road graders. That deposited by wagons was levelled by the graders. The layers were 6 inches thick, and were sprinkled with hose supplied by pipes and pumps.

The water was at first secured by the construction of temporary earth embankments to store the storm water of Owl Creek; but this supply was so precarious that the contractor bored two artesian wells, each 1,430 feet deep, which solved the problem.

The earth of which the dam is composed being nearly pure clay, care was taken not to supersaturate it. The water was in general limited to the quantity barely sufficient to make rolling effective and permit consolidation. In a few spots leaky pipes, or other carelessness on the part of the contractor, formed boggy places, but these were very limited in number and extent, and the surplus water was absorbed by the surrounding earth. Borings in the solidified embankment with a post auger showed uniformly that the earth was barely moist and so compact as to receive a high polish. In the progress of the work a few briquets were made by pressing the moist clay into briquet molds and drying them in the sun. Some of these clay briquets showed a tensile strength of 75 pounds per square inch. All the indications are that the clay embankment is very stable and practically impervious to water. The earth occupies about 1 per cent more space in embankment than in excavation.

The rolling was done at first by a 12-ton road roller, but this was later succeeded by 21-ton traction engines, with the rear wheels widened on the rim to 3 feet each. These were more effective and satisfactory than the road roller. It was recognized as impossible to consolidate the bank to the extreme edge

by rolling, owing to the lateral movement of the earth under pressure. For this reason the specifications required the bank to be built 1 foot beyond the desired lines on the reservoir side, and this extra foot of loose material to be later removed before placing the pavement.

PAVEMENT OF OWL CREEK DAM

No rock occurs anywhere in the neighborhood of the dam, and it was provided that the water slope be paved with concrete blocks to protect it from wave action. The blocks were 6½ feet long, 5 feet wide, and 8 inches thick, laid in horizontal courses breaking vertical joints. Under this pavement was placed a gravel base, consisting of 1 foot of natural gravel next to the earth, and over this 1 foot of screened gravel.

The nearest available gravel pit was near the river, about 6 miles from the dam. At that point the blocks were manufactured and later hauled to the dam. The gravel used in the dam was hauled from the same point.

The blocks were laid with care, forming a very smooth surface, with cracks varying from zero to a few of nearly an inch, but most of them less than ½ an inch, and the average perhaps ⅓ of an inch.

An accident to the pavement occurred in 1912, which is of interest. On the night of April 13, 1912, when the water in the reservoir stood at elevation 2,959, a very high wind from the west, estimated at 70 miles per hour, caused waves in the reservoir 8 or 10 feet in height to beat against the concreted slope of the dam. This attack from without was resisted successfully, but at the culmination of the storm, which occurred between midnight and 4 A.M., April 14, the receding waves periodically relieved the weight on the concrete blocks so that the back pressure of the water behind the pavement displaced several blocks in the seventeenth course, the top of which is at elevation 2,958. The displacement of these blocks permitted the waves to act upon their gravel foundation and gradually undermined the blocks above as far up the slope as the waves could act, viz.: at some points to elevation 2,973, and also laterally to a greater extent, allowing the blocks to settle down against the clay slope, forming an irregular pavement.

In all, about 250 blocks, out of the 16,000 forming the pavement of the dam were undermined and more or less displaced, but none were lost or broken. The total gravel removed was about 600 cubic yards, and only a small quantity of clay was missed, as this resisted the wave action remarkably well.

The wind that caused the initial displacement of blocks was estimated by the project engineer to be blowing at the rate of 70 miles per hour, but this is uncertain, as no actual observations of the rate were made at this point. The anemometer observations taken once a day at the experiment farm, 12 miles east of the dam, showed the mean wind velocity for the twenty-four hours which preceded 7.30 A.M., April 14, as 24.6 miles per hour. On the same night wind velocities were reported in Denver as high as 75 miles per hour, and considerable damage was reported on concrete paving of dams, and on other structures.

The water at all times stood in the gravel against the clay under the concrete blocks, at about the same height as the general level of the water in the open reservoir. The sudden recession of the high waves removed the water pressure from the outside of the blocks, leaving an unbalanced hydrostatic pressure behind, equal to the difference between the trough of the wave and the mean level of the reservoir. The head thus produced probably reached 4 or 5 feet, producing a pressure more than double the weight of the block. This was partly relieved by the water spurting through the cracks in the pavement, and resisted by the friction of adjacent blocks, but where these were insufficient, the block was lifted from place, and allowed the waves to wash out the underlying gravel and to undermine the adjacent blocks.

The trough of the largest waves came about the bottom of the seventeenth course, so that the maximum back pressure was concentrated upon this course. No breach was anywhere found that did not evidently originate in the removal of a block from the seventeenth course. Where irregularities of slope made this course about 1 foot lower than in other places, no breach was made, the pressure being there divided between two courses. It is evident that if adjacent courses had been firmly fastened together, or if the blocks had been twice as wide up and down the slope, no damage would have occurred, and this suggests the obvious remedy, that of fastening each course to the one

above and below. As only a small portion of the course actually attacked was injured, it is evident that blocks that were not moved were held in place by their own weight, assisted by the friction of adjacent blocks. It thus appears that in the pavement in general most of the blocks have sufficient frictional resistance to hold them, and if this friction can be materially increased all over the dam, the blocks would be secure. On this theory, the following repairs were carried out.

The ruptured portions of the pavement were replaced in monolithic concrete on a base of unscreened gravel. The arrangement of the blocks in horizontal courses, with vertical joints broken, places each corner of a block at a three-way joint. At each such joint, a 1½-inch hole has been drilled, and this hole filled with grout. All joints sufficiently open to be grouted have also been filled. This work was done mainly in the spring of 1913, when the blocks were approximately at their minimum volume, due to temperature. In all, 18,000 holes were thus drilled and grouted, at a cost of about 5 cents each.

On May 10, 1916, under the influence of a still heavier and more protracted storm, reaching at times about 100 miles per hour, another and similar breach was made in the pavement higher up the slope, affecting the twenty-second course instead of the seventeenth.

The damage itself was not great, but it demonstrated that the precautions above described were inadequate. Probably the only entirely effective measures will be to make complete cement-mortar joints at all block junctions. This will require the removal and replacement of all blocks within the danger zone. In replacing the blocks, the length of block will extend up and down the slope, instead of horizontally. This has been done.

After the reservoir was placed in service some seepage appeared near the down-stream toe in the natural ground. To guard against softening the foundation and thus permitting sliding, a drainage system was installed to carry away the water. This consists of a trench 2,550 feet long, 3 feet wide, and 12 feet deep, in which is placed a line of 12-inch vitrified pipe with open joints. It is surrounded with screened gravel, and the trench is filled with gravel. At intervals of 50 feet in the bottom of this trench, wells were provided, extending to a depth of about 20 feet below the bottom of the trench and filled with gravel. These provisions

have proved effective in drying up the ground near the dam. The drain discharges into Owl Creek a steady flow of about $\frac{1}{10}$ of a cubic foot per second. It appears that this water comes from a sand stratum under the dam which was uncovered in one of the borrow pits during the construction of the dam.

NORTH CANAL

The canal for irrigating the lands on the north side of Belle Fourche River, below the reservoir, is about 45 miles long and heads at the north outlet conduit. Its capacity is 1,300 cubic feet per second to the wasteway channel which it crosses $\frac{1}{2}$ mile from the dam, and here are located spillway gates. Beyond this point the capacity is 650 cubic feet per second, the bottom width is 28 feet, and the water depth 7 feet. The heaviest work on this canal consists of a cut about a mile from the dam, which has a maximum depth of 50 feet for a considerable distance. Most of this cut was excavated during freezing weather when work on the dam was forbidden, and the steam shovel employed on the dam was used. The balance of the excavation on the North Canal was mostly done with teams and fresnos.

About 8 miles from the head of the North Canal, just before crossing Indian Creek, it is provided with a sluiceway, and a drop of 36 feet into Indian Creek, by which the water can be quickly turned out of the canal in case of a break. The water is discharged by the sluice into Indian Creek about 200 feet above the flume crossing. The flume across Indian Creek is 43 feet above the creek-bed, and 1,300 feet long. It is built of galvanized steel and supported on wooden bents, anchored to concrete bases. The flume is semicircular with inside diameter of 10 feet and 10 inches.

Its theoretical maximum water depth is 10 feet, 7 inches, and its rated capacity about 500 cubic feet per second, the mean velocity being about 11.5 feet per second. It begins with an intake conduit of reinforced concrete 93 feet in length, and terminates in a similar channel 50 feet long.

The total fall of the water surface from the earth section above the flume to earth section below is 8.64 feet. A coefficient of roughness for use in the Kutter formula was taken as .012 for the flume and smooth concrete section. A few baffles are

provided at the lower end of the exit section, consisting of rocks set in the concrete, and projecting 4 to 6 inches, in order to reduce the velocity before it enters the earth section.

On account of the long wagon haul for concrete materials, the culverts used to convey small drainage channels under the canal are built of galvanized, corrugated steel pipe, with concrete terminals and cut-off collars.

In order to avoid building a lateral parallel to the main canal, the farm units along the canal were mostly provided with a separate turnout from that canal consisting of a 12-inch vitrified clay pipe with concrete inlet and outlet, controlled by a steel gate working in a steel frame, and moved by means of a screw stem inclined 20 degrees from the vertical. Most of these outlets were 12 inches in diameter.

SOUTH CANAL

The South Canal heads at the south outlet of the Belle Fourche Reservoir, and runs in a southerly and easterly direction, a total length of about 45 miles. It furnishes water to 4,000 acres west of Owl Creek and to 28,000 acres south of the Belle Fourche River.

At its head the bottom width is 18 feet, the water depth is 5 feet, and the capacity is 350 cubic feet per second. This is reduced as laterals are taken out. The grade is 1.56 feet per mile.

The South Canal crosses the Belle Fourche River by means of a pressure pipe or inverted siphon 3,565 feet in length, working under a maximum head of 65 feet, and an average head of 50 feet. It is built of reinforced concrete, and has an internal diameter of 5 feet. The shell is 8 inches thick, and is reinforced with 305,000 pounds of ½-inch and ⅝-inch steel bars.

During construction in 1908 the water of the Belle Fourche River was diverted at the diversion dam and carried through the feed canal to Owl Creek, which discharged it into the river far below the crossing of the South Canal. For constructing the pressure pipe, the remaining water was diverted by means of a cofferdam. The pipe is founded in shale for most of its distance. It was built as a continuous structure, using collapsible steel interior forms. Five expansion joints are provided.

The inlet and outlet structures are both of reinforced con-

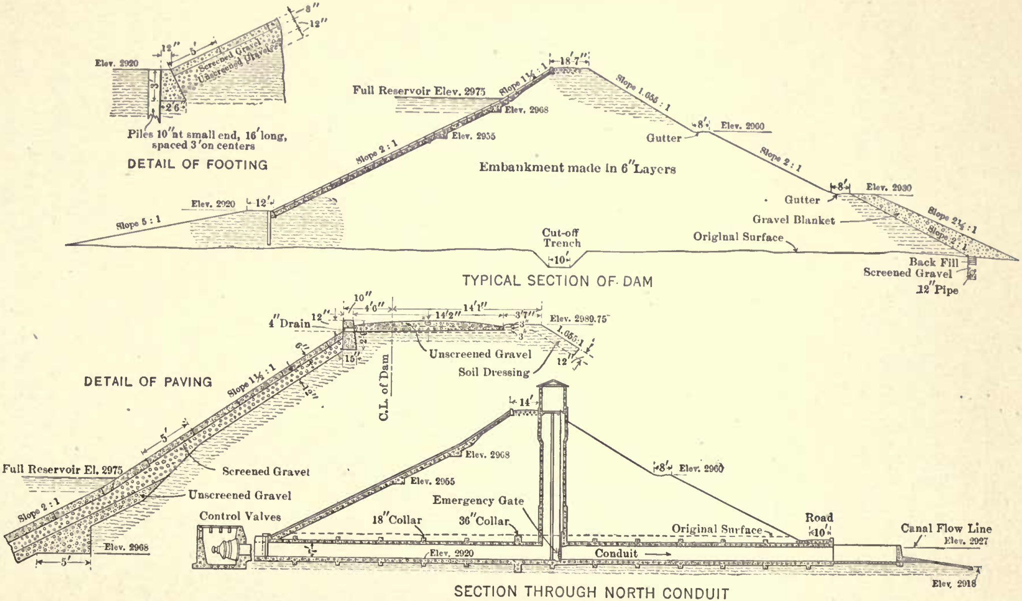


FIG. 95.—Sections of Owl Creek Storage Dam, Belle Fourche Project, S. D.

crete, the former being protected by a steel grizzly to prevent the entrance of drift.

At the lowest point of the crossing is placed a round, 24-inch gate valve for use as a blow off when it is desired to empty the pipe. This pressure pipe has shown very little leakage and has given entire satisfaction in service.

About 2 miles east of the river crossing, the south bank of the river crowds the foot of a high bluff, through which the canal is carried in a tunnel 1,306 feet in length. It is horseshoe in shape, and has a maximum width of 9½ feet, and a center width of 10½ feet. It is constructed through soft, laminated shale, and required timbering throughout. It was excavated from both ends by one crew; while drilling was in progress at one end the muckers were employed at the other. Hand drills were used, and as blasting was done at the end of the shift, no ventilating plant was required. The tunnel was lined with concrete, the average thickness of lining being about 8 inches.

The South Canal is carried across Anderson draw by means of a reinforced concrete pressure pipe 425 feet long, under a head of about 45 feet, and under Whitewood Creek by means of another pipe 350 feet long, under a head of 15 feet.

The lateral system of the Belle Fourche Project includes nearly 400 miles of lateral canals, and over 1,000 small structures. It was designed to deliver water to each unit of 80 acres or greater, and to carry a cubic foot per second to each 30 acres, with a minimum canal capacity of 4 cubic feet per second, so that by rotation every irrigator can use that head of water if he chooses. The velocities are kept within 3 feet per second, and surplus grade used up in vertical drops. Some of the small structures were built of timber. The lateral system cost about $5 per acre on an average for the land served.

AGRICULTURAL RESULTS

The lands of the Belle Fourche Project were about one-half public lands and about one-half were in private ownership when the project was started. The public lands were mostly entered by settlers some time before the water was available, and when the project was opened the farm unit on public lands was fixed at 80 acres. Where settlers were provided with sufficient capital

to properly prepare and cultivate the soil, good results have been achieved. In a few places seepage has appeared, and some drainage works will be required to protect such places against alkali.

The Belle Fourche Project was largely planned and built by R. F. Walter. The Owl Creek Dam was in the immediate charge of W. W. Patch.

CHAPTER XIX

STRAWBERRY VALLEY PROJECT

DESCRIPTION

One of the oldest irrigated regions of modern America is the valley lying east of Salt Lake and Utah Lake.

The Ogden, Weber, Provo and Spanish Fork Rivers, and some intermediate creeks, gather snow waters from the high peaks of the Wasatch Range and flow westward across a fertile plain to the lakes mentioned. The moderate size of these streams, the steep grade on which they emerge from the mountains, and the smooth, fertile plains along their banks presented nearly ideal conditions for easy diversion, and their habit of flow, in which the gentle rise in spring and culmination near midsummer roughly approximated the demands of irrigation, insured large results from their skilful use.

Thus, highly favored by natural conditions, the industry and devotion of the Mormon settlers achieved early and remarkable results, and long ago the available summer flow of these streams was fully appropriated in normal years, and in low water years serious shortage was suffered by many of the later appropriators. This condition was especially emphasized in the southern end of the Valley, where the area of valley land was far greater than the dependable water supply.

To relieve this situation and also to furnish water to additional areas in the vicinity, the Reclamation Service undertook to store the waters of Strawberry Creek, a tributary of the Green River System, and to bring these waters through the Wasatch Range into the basin of Spanish Fork River.

POWER DEVELOPMENT

The first construction undertaken on the Strawberry Project was the diversion of Spanish Fork River and the construction of a power canal with a capacity of 500 cubic feet per second. This

FIG. 96.—Spillway of Power Canal in Winter, Strawberry Valley Project, Utah.

canal is to serve also the main irrigation canal but was constructed early in order to develop power for the construction of the tunnel and the other power needs of the project. At 3¼ miles below the heading, the water is dropped 125 feet through a 5½-foot steel penstock and generates power for transmission to Strawberry Dam and Tunnel. The plant also supplies current for lighting several towns in the vicinity.

The plant consists of two horizontal turbines of 800 horse-power each, direct connected to two 500 K. V. A., 3-phase, 60-cycle alternators, generating current at 11,000 volts, and two horizontal turbines of 100 horse-power each, direct connected to exciter units generating 45 kilowatts each at 125 volts. The current is transformed to 22,000 volts for transmission to Strawberry Valley, but is transmitted to the neighboring towns at 11,000 volts, and substations at those towns step this down to 2,300 volts for local distribution.

SPANISH FORK DIVERSION DAM

The diversion dam on Spanish Fork River is a concrete overflow weir, 16 feet high and 70 feet long. It is provided with concrete sedimentation basins through which the water is drawn and allowed to settle, there being two of these so that one can be flushed out while the other is in use. A similar pair of sediment basins is provided at the penstock of the power-house.

The canal above the power-house traverses a steep mountain-side and passes through several tunnels. In some places the slope is so steep that the excavation of the canal renders the ground above insecure and it becomes necessary to provide a covering for the canal to prevent its being filled by slides.

STRAWBERRY RESERVOIR

Strawberry Creek drains a portion of the eastern slope of the Wasatch Range and flows into the Duchesne River, a tributary of the Green, which lower down joins the Grand to form the Colorado. In its lower portion Strawberry Creek flows through a wide, beautiful mountain valley, and then enters a narrow gorge, forming a combination of circumstances favorable for the storage of water in a reservoir by closing the gorge with a dam.

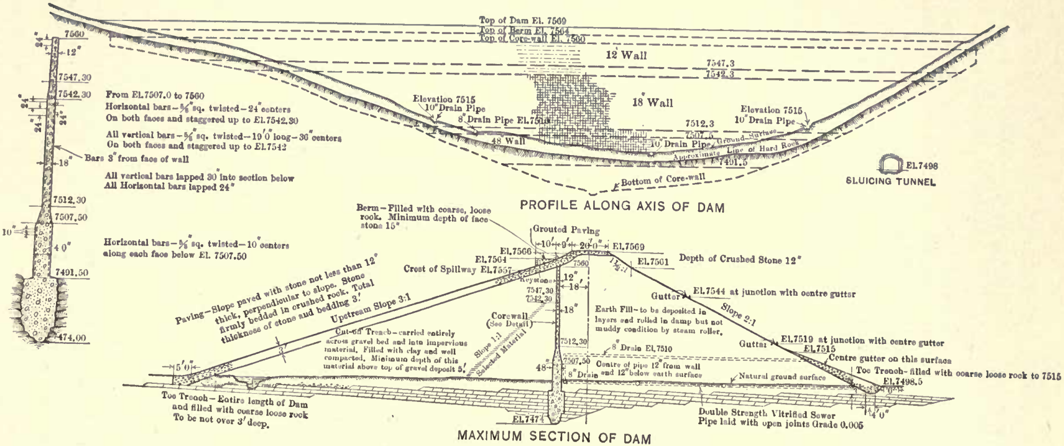


FIG. 97.—Elevation and Cross-Section of Strawberry Dam, Utah.

The reservoir as built has a surface area of 8,200 acres, and a capacity above the sill of the tunnel outlet of 250,000 acre-feet. The main supply of water is from Strawberry Creek but this is reinforced by Indian and Trail Hollow Creeks, which are diverted into the reservoir by means of canals. The total area tributary to the reservoir as thus increased is 175 square miles, all of which is above 7,500 feet in elevation. and receives a heavy snowfall every year.

The water is drawn from the reservoir through a tunnel 19,845 feet long driven through the mountain range to the westward.

An incomplete record of nine years on this water supply indicates a maximum of 150,000 acre-feet, a minimum of 49,000, and a mean of 75,000 acre-feet. It is probable that a longer record will show much wider extremes. A series of plentiful years will fill the reservoir and provide a supply for a series of dry years.

Strawberry Valley Dam.—The gorge at the lower end of Strawberry Valley, called "The Narrows," is closed by an earthen dam 60 feet high. The top width is 21 feet, the water slope 3 to 1, and the down-stream slope 2 to 1. It was provided with a core-wall of reinforced concrete 16 feet up-stream from the axis of the dam, embedded in bed-rock at the base, and extending to an elevation 9 feet below the top of the dam and 1 foot above spillway lip. The bed-rock trench was carried down to a maximum depth of 20 feet, and varied from 5 to 10 feet in width. This was filled with concrete, and, anchored into this mass, a reinforced concrete wall, 40 inches thick, was built up 10 feet, above which it gradually narrowed to a thickness of 18 inches for 28 feet, and then narrowed to 12 inches to the top. The principal function of the core wall was to guard against the attacks of burrowing animals. It is not expected that a watchman will be kept at this dam, as it is remote from the outlet works.

The up-stream slope is protected by a 2-foot layer of crushed rock and a pavement of hand-laid stones averaging about 12 inches in thickness. Along the water slope of the dam at the spillway level, a heavy stone terrace 3.3 feet in height is built on the pavement, forming the lower edge of a berm of 11.4 feet, to break the wave action in case of storms, and the upper 3 feet of the face is given a slope of 1 to 1.

The down-stream slope is protected by a layer of rough rip-

rap, extending from a level 10 feet below the spillway to the base. It is about 3 feet thick at the base, diminishing to about 1 foot at the top. The down-stream portion of the dam is provided with an elaborate system of tile drainage to keep down any percolating waters and prevent the saturation of this portion of the dam.

A spillway was excavated through the left abutment of the dam, the bottom of which was finished 10 feet below the top of the dam, having an intake lip 80 feet long, leading into a concreted channel, which discharges into the creek-bed below the dam. The spillway lip is surmounted by a concrete bridge of four spans.

A sluicing tunnel was driven through the left abutment, through which the creek was diverted during construction, and by which the reservoir can be emptied if necessary for repairs in the future. This tunnel above the gates is 8 feet square with an arched top with a rise of about 3 feet. Below the gates it is about 10 per cent larger than this. It is controlled by two ordinary sluice-gates, each 4 feet by 6 feet.

Power for the construction of the dam was transmitted from the power-plant on Spanish Fork River described elsewhere. It was in the form of a 3-phase, 60-cycle current at a voltage of 22,000, which was stepped down to 440 volts for use with induction motors.

A 225-horse-power direct current generator was provided and direct current was used on all hoists. A two-drill air-compressor was used to provide power for driving the sluicing tunnel.

A cableway was provided spanning the dam site, directly over the core wall, with 826 feet between towers. The crusher and storage bins were located directly under the cable.

After the construction of the road to the dam site, work was started on the diversion tunnel, and soon after the stripping of the abutments of the dam site began. As soon as the tunnel was completed, the river was turned through it, and the stripping of the river-bed began. It soon developed that the sand and mud in the river-bed were underlaid by a stratum of gravel and a cut-off trench was located 150 feet up-stream from the core-wall, and this extended across the river and for some distance up the hillsides, to prevent percolation under the embankment. This trench varies from 6 to 10 feet in width and was carried

down into the bed-rock, which was hard limestone somewhat seamy.

The bottom of this cut-off trench was covered with 6 to 12 inches of concrete and a cut-off wall carried up from this with a thickness of 2 feet and brought up 2 feet higher, and puddled

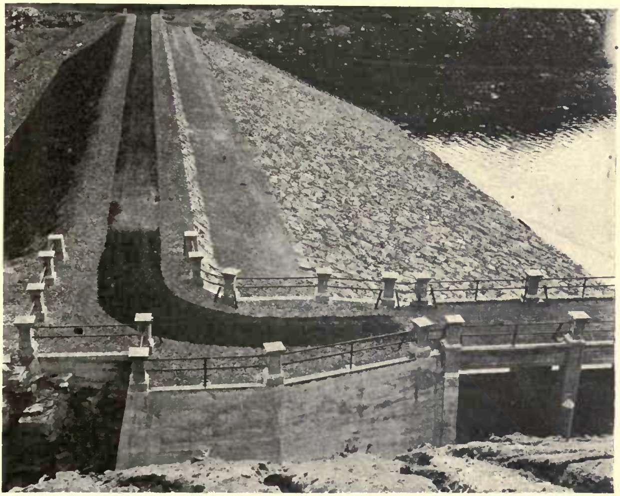


FIG. 98.—Strawberry Dam and Spillway, looking south.

clay tamped on both sides. A small spring of water coming from the rock in the trench on the north bank gave some trouble, and was gathered in a 2-inch pipe and carried through the bank and core wall.

The excavation for the core wall averaged about 8 feet in width and was carried about 20 feet into bed-rock, on account of the seamy water-bearing condition encountered. Plum rock was freely used in the base and the thicker parts of the core wall. The concrete was dumped in the core wall direct from the cableway.

The earth for the embankment was obtained from borrow pits south of the dam site. It was loaded by elevating graders into dump wagons, hauled and dumped on the dam. Two graders

and fifty dump wagons were employed. The earth was spread with a road grader to a thickness of about 4 inches, sprinkled with hose and rolled with a 10-ton traction engine. It was the aim to provide about 14 per cent moisture in the earth before rolling.

STRAWBERRY DAM COST SUMMARY

Clearing and cleaning dam site	$ 2,665
Temporary diverting dam	703
Sluicing tunnel and gate shaft	40,281
Core-wall trench excavation	7,708
Reinforced concrete core-wall, 2,128 cu. yds at $18.63.	39,646
Earth embankment, 108,415 cu. yds. at 63 cents	68,286
Tile drains in foundation	2,328
Concrete cut-off wall	3,955
Excavating toe trench	234
Rock-fill in toe trench	1,116
Paving up-stream slope, 6,985 sq. yds. at $3.69	25,786
Soil dressing down-stream slope	784
Paving down-stream slope	1,400
Roadway across dam	1,249
Wasteway	50,755
Sluicing-gates and hoists	7,503
Berm	1,942
Concrete bridge across wasteway	8,971
Hydraulicing clay blanket	1,721
Total	$267,033

Indian Creek Dike.—A low saddle separates the Valley of Strawberry Creek from that of Indian Creek, and to prevent the Strawberry Reservoir from overflowing into Indian Creek it was necessary to provide an earthen dike with a maximum height of 38 feet and a length of 1,311 feet. It has a top width of 20 feet, a maximum bottom width of 206 feet, a down-stream slope of 2 to 1, and a water slope of 3 to 1, below spillway level, and 1 to 1 above that level. It is provided with a reinforced concrete core-wall 18 feet up-stream from the axis of the dam, carried 3 feet into the ground and connected with a row of Wakefield sheet piling 12 feet deeper.

A drain of 8-inch tiling follows the ground on the lower side of the core-wall and discharges through three branch drains leading to the down-stream toe, in order to prevent the satura-

tion of the lower half of the dam from leakage under or through the core-wall.

The water slope of the dike is protected from wave action by a layer of 2 feet of broken stone and 1 foot of large hand-laid rock. A berm is provided about the spillway level, with a vertical offset at its lower edge to break the waves. Above this berm the slope is 1 to 1.

A trench was provided along the up-stream toe of the dam, 5 feet wide and 2½ to 3 feet deep, and filled with broken rock. Excavation for the foundation of the core-wall uncovered a stratum of quicksand, and to cut off percolation through this the sheet piling was provided, which also served as a support for the core-wall.

A cut-off trench was staked out and excavated on the reservoir side of the core-wall and distant therefrom 45 feet. It had a depth of 3.5 feet, a bottom width of 6 feet and side slopes of 1 to 1. The entire base of the dike was scored with furrows 6 inches deep, parallel to the axis of the dike. The earth for the embankment was loaded by elevating graders into dump wagons holding about 1½ cubic yards each. After dumping, the earth was spread in 6-inch layers and sprinkled with a sprinkling cart at first, but later a 2-inch pipe was laid along the core-wall with taps every 100 feet, and the sprinkling was done with a flexible hose, this method giving more uniform results. After sprinkling the layer was rolled by means of a corrugated iron pipe filled with concrete weighing 2,000 pounds for each foot of tread.

Indian Creek and Trail Hollow Feed Canals.—Indian Creek and Trail Hollow are two creeks to the southward of the Strawberry Creek, which are diverted into Strawberry Reservoir in order to increase the storable water supply. The waters of Trail Hollow are carried to Indian Creek in a canal about 4 miles long, and below its discharge the water is diverted from Indian Creek and carried about 2 miles to Strawberry Reservoir. Trail Hollow is a small creek and the canal diverting its water has a bottom width of 12 feet, a water depth of 3 feet, and a capacity of about 120 cubic feet per second. The Trail Hollow Diversion is a simple concrete structure with a sluicing culvert controlled by a cast-iron gate 2 feet by 3 feet. The intake to the canal is controlled by flash-boards of 5 feet 4 inches span, there being two such openings.

The canal carrying the combined waters of both creeks from Indian Creek to the reservoir has a bottom width of 22 feet, a water depth of 7 feet and a capacity of over 500 cubic feet per second.

The diversion of Indian Creek is accomplished by means of a long earthen dike built across the flood plain and a concrete weir in the channel of the stream. Two small sluice-gates are placed against the left bank, adjoining the intake of the canal, which is controlled by six gates. Both the weir and the head-gate structure are surmounted by concrete bridges and a curtain wall closes the space between the head-gates and the bridge so as to confine the intake opening strictly to the size of the gates and prevent excessive fluctuation of the quantity of water entering the canal, as the head varies.

The Indian Creek Canal terminates at the reservoir in a long concrete chute. At the crossing of Horse Creek, a bank is thrown across the creek and its water taken into the canal.

Cost of Indian Creek Dike

Earthen embankment in place, 101,167 cu. yds. at 40.5 cents	$ 40,989
Core-wall trench excavation, 411 cu. yds. at $1.41	580
Concrete core-wall, 1,516 cu. yds. at $16	24,263
Rockfill in berm, 878 cu. yds. at $4.28	3,759
Rockfill in toe trench, 1,259 cu. yds. at $2.87	3,619
Paving up-stream slope, 11,041 sq. yds. at $3.34	36,858
Drains, 1,445 feet at $1.09	1,569
Placing steel, 77,677 lbs. at $0.019	1,468
Soil dressing, down-stream slope, 1.681 acres at $576.66	969
Roadway, crushed stone, 850 cu. yds. at $3.09	2,623
Roadway, earth covering, 250 cu. yds. at 79 cents	197
Lumber in place, 6.772 M, at $59.03	400
Excavation drainage channel, 2,000 cu. yds. at 25 cents	500
Reinforced concrete in culvert, 7 cu. yds. at $22.86	160
Sheet piling	1,296
Total	$119,250

STRAWBERRY TUNNEL

This tunnel extends from the margin of Strawberry Reservoir on the east slope of the Wasatch Range to the headwaters of Diamond Creek, a tributary of Spanish Fork River on the western

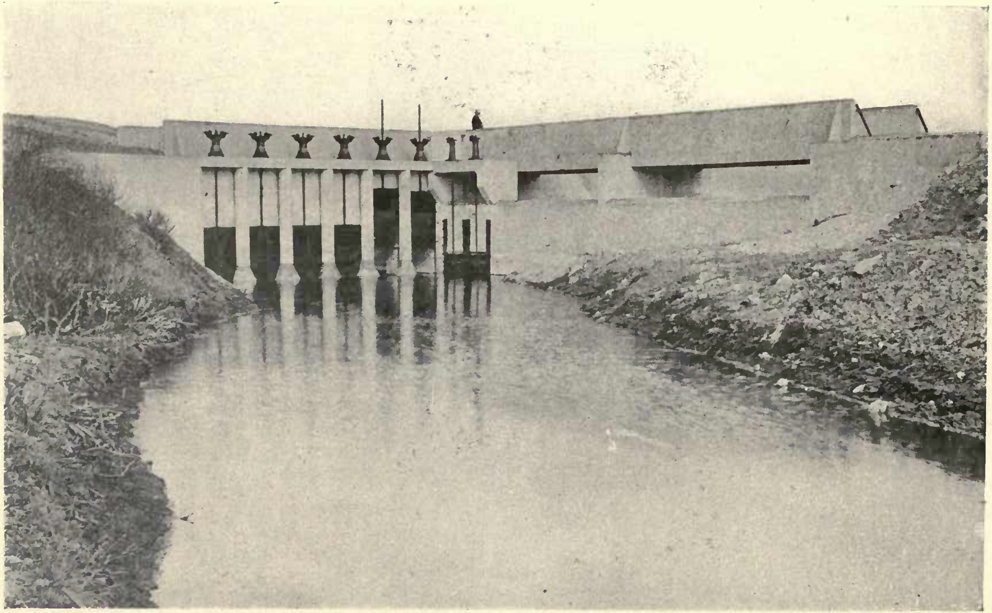


FIG. 99.—Intake of Indian Creek Feed Canal, Strawberry Project, Utah.

slope of the same range, and has a total length between portals of 19,897 feet.

The slope of the tunnel is .003, and its theoretical capacity, operating as an open channel, is 500 cubic feet per second. It is nearly square in section, with an arched top, the width being 7

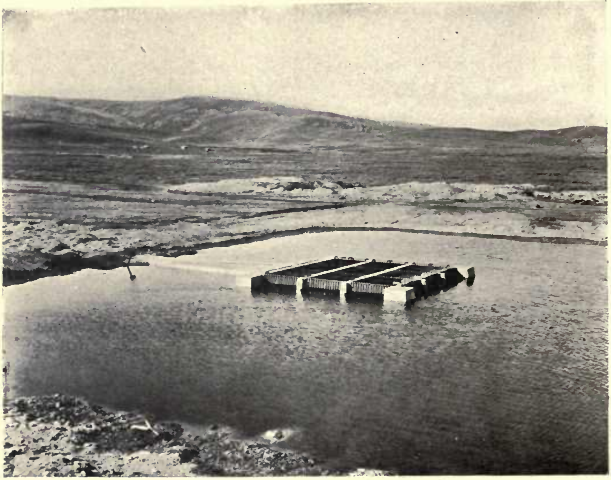


FIG. 100.—Intake of Strawberry Tunnel, at East portal, north End of Reservoir, Strawberry Valley Project.

feet and height to the spring of the arch being 6½ feet in the finished tunnel. The arch has a rise of 2 feet. The rock encountered was mostly sandstone and limestone, usually hard but containing many seams and many springs of water, with occasional strata of shale which swelled badly, gave much trouble and required heavy timbering. Most of the tunnel required timbering.

When the project was undertaken, the first work started was the power canal, destined to develop power for construction purposes. To avoid delay and also to develop methods, work on the west portal of the tunnel was started soon after, this being the feature requiring most time. Gas engines were used to develop power, 70 horse-power in all being installed, and electric

drills were used at first. These were later abandoned in favor of compressed air. The tramming was done by horse-power. About 1,600 feet of tunnel was thus driven, which developed the character of material to be encountered and methods of handling it. The increased amount of power required caused this work to be shut down to await the completion of the power canal and plant.

As soon as these were completed, electric current was delivered over $26\frac{1}{2}$ miles of transmission line at a voltage of 22,000 and stepped down at the tunnel substation to 2,200 volts, at which tension it was supplied to the induction motors.

A motor of 125 horse-power was belted to a 427-cubic-foot air-compressor to supply compressed air to the drills, and a motor-generator set supplied direct current at 250 volts for lighting, driving small motors in the machine shop, and for operating the tramway in the tunnel. As soon as the tunnel was driven to a distance of 7,000 feet from the west portal, a chamber was provided there in which was installed another motor-generator set of 175-horse-power capacity to supply direct-current power for the tramway, blowers and lights.

Most of the tunnel was driven from the west heading for the sake of economy. That heading was the nearest to the source of power and all other supplies, and the road to the east portal was closed either by snow or mud the greater part of the year. The tunnel was a wet one, and its grade allowed the water to drain to the west, while all water would have to be pumped from an eastern heading. The borings near the east portal developed several artesian wells, indicating serious trouble with water there. When a small amount of work was done on the eastern end, it was found that the water problem was not as serious as expected.

After electric power became available in January, 1909, work was started at the western heading with one shift, which was soon increased to two and later to three. Two $3\frac{1}{4}$-inch air-rock drills were used mounted on columns. Air was used at pressures from 85 to 90 pounds per square inch. It was transmitted through a 4-inch pipe, and an auxiliary receiver was installed at the 5,000-foot station in the tunnel to steady the pressure at the drills. This receiver was later moved nearer the heading as the tunnel advanced. Each shift was required in eight hours to clean up the heading, drill and shoot one complete round of drill holes, usually consisting of 18 holes, from 4 to 7 feet deep.

The ventilation of the tunnel was accomplished through a 14-inch pipe made in 16-foot lengths, and kept about 60 to 80 feet from the heading to avoid injury in blasting. A blower was installed 4,000 feet from the portal and revolved at full speed after each blast in such a way as to suck the smoke and gases from the heading. After ten to twenty minutes, the blower was slowed down to ¾ speed for the rest of the time. A second

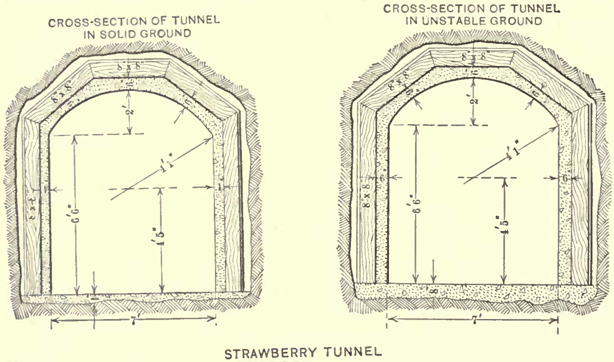


FIG. 101.—Cross-Sections of Strawberry Tunnel, Utah.

blower was installed when needed. about 11.000 feet from the portal.

Horse haulage was employed to Station 35. Beyond this point the excavated material was hauled out of the tunnel in steel cars of 47-cubic-feet capacity by electric locomotives on a track of 25-pound rails, 2 feet apart. Direct current at 250 volts was supplied to the locomotives by a 0000-copper wire carried on special pine poles fastened to the cross-ties of the track at 40-foot intervals to avoid moving the wire when concreting. When the loaded cars arrived at the dump below the west portal, a bail was attached to two lugs provided for the purpose, and the car lifted from the track by a 7½-ton derrick, swung out over the edge and dumped, and then returned to the track. The derrick was moved once a month as the dump advanced and the track was brought up within reach.

A long approach cut was necessary to connect the Strawberry Reservoir with the east portal of the tunnel. On account of the very wet material a drag-line excavator with a 70-foot boom

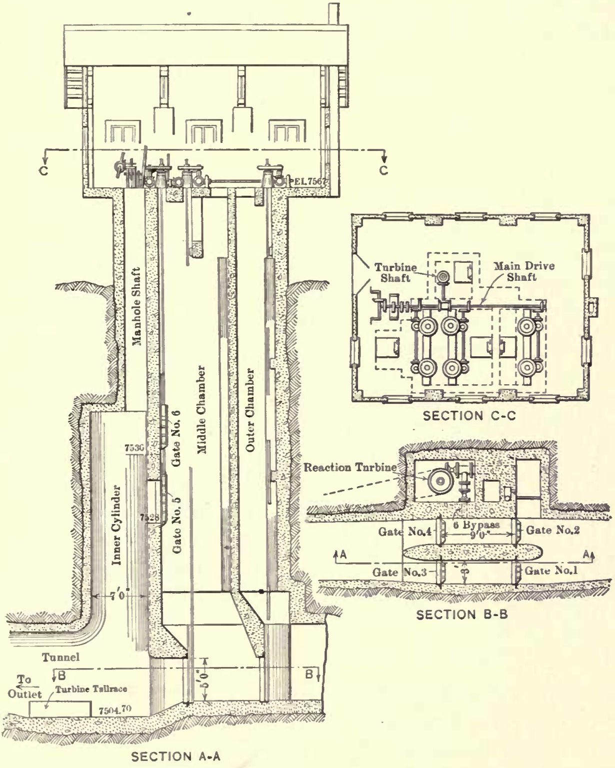


FIG. 102.—Strawberry Tunnel Controlling Works.

was selected as best adapted to the work. A derrick with a 60-foot boom was also provided which served material needed in the cut.

The material encountered was so soft and unstable that it would not stand on any reasonable slopes, and it was necessary to make a cut and cover section instead of an open cut. The section adopted was a circle with an inside diameter of 8 feet and 2 inches, connecting with the tunnel section by warped surfaces. The open cut was about 600 feet and the cut and cover section 760 feet. The latter was built on a 1 per cent grade to save excavation and shorten the tube.

The total length of tunnel excavated from the east portal was 2,686 linear feet. about two-thirds of which was timbered.

Fig. 103.—Flow of Water in Strawberry Tunnel.

The intake to the conduit was merely a system of columns and beams supporting a steel grating to prevent debris from being carried into the tunnel.

The control works are installed in a shaft located on the hillside above the water line of the full reservoir, and consist essentially of two sets of two gates each, 3 feet wide and 5 feet high, operated by an 18-inch reaction turbine water-wheel. A reinforced partition or elongated pier 2 feet thick serves to divide the tunnel into two tubes for a distance of 18 feet.

Complete Cost of Strawberry Tunnel

Control works and intake	$ 99,631.53
Driving tunnel, including timbering	778,984.57
Lining tunnel	297,606.16
Clearing sites for outlet structures	2,630.64
Portal arch	3,806.52
Outlet weir barrier	6,461.44
Stilling basin	1,405.74
Two permanent cottages, east portal	6,542.83
Other improvements at east portal permanent camp	1,857.95
Total	$1,198,947.38

19,897 feet at $60.25 per foot

Progress in Strawberry Tunnel

West Portal:	
1906 and 1907	1,613 feet
1909	3,892 "
1910	5,031 "
1911	3,491 "
1912	2,382 "
Total from west portal	16,409 feet
Excavated at east portal	2,686 "
Cut and cover	760 "
Grand total	19,855 feet

Stilling Basin.—At the western portal of the tunnel a stilling basin was provided to check the velocity of the water emerging from the tunnel and permit its measurement over a weir. The basin was 130 feet long, and had a bottom width of 40 feet with side slopes 1 to 1. The bottom of the tunnel at the portal is at elevation 7,451.95, and the crest of the measuring weir is 7,453. The weir is 14 feet long and stands 7 feet above the bottom of the pool at its base. The bed-rock below the weir was paved with concrete averaging about 6 inches thick.

DISTRIBUTION

The distribution of the waters from the Strawberry Reservoir is made from Spanish Fork River, so that advantage can be taken of all unappropriated flood waters and stored water used to supplement them. The largest unit of the project com-

prises the irrigable land commanded by the "High Line" Canal, which is an extension of the power canal already described. The capacity of this canal from its head to the power house is 500 second-feet. At this point it decreases to a capacity of 295 second-feet, having on the steep side hill a bottom width of 12 feet and a water depth of 5.6 feet, and on gently sloping ground a bottom width of 20 feet and a water depth of 4.1 feet, the grade in both cases being .0004. The capacity decreases as lat-

Fig. 104.—Strawberry Tunnel, showing Steel Forms for Concrete Lining.

erals are taken out, and the canal arrives at Station 1,040 with a capacity of 215 second-feet. Here it passes into a rock cut, lined with concrete to save excavation. Emerging from this cut the canal branches, and the main branch is dropped 15 feet through a drop chute 414 feet long and crosses the saddle of Goshen Pass through a pressure pipe under the Denver & Rio Grande Railroad to water lands on the eastern slope of West Mountain. The pressure pipe is 36 feet in length and 36 inches in diameter, and is built of cast iron, with an estimated capacity of 30 second-feet. A lateral of 60-second-feet capacity

FIG. 105.—Measuring Weir, and west Portal, Strawberry Tunnel, Utah.

branches off above the chute and continues into Goshen Valley, where it sends off branches to cover about 11,000 acres of land. From this division point at Goshen Pass the system is nearly all concrete-lined canals or pipes, for saving water and excavation, and providing against excessive erosion from high velocities introduced by the slope of the country served.

The total area of irrigable land under the "High Line" is 24,000 acres.

Other areas to which it is proposed to deliver storage water have some flood water supply already from Spanish Fork and Hobble Creek. It is expected that such supplementary supply of storage water will be furnished to about 25,000 acres of land.

The Strawberry Project was built by J. T. Lytle under the direction of J. H. Quinton as Supervising Engineer, later succeeded by Louis C. Hill.

CHAPTER XX

OKANOGAN PROJECT

DESCRIPTION

This is a small enterprise in northern Washington not far from the Canadian line.

It provides for the storage of water by a dam on Salmon River below Conconully, Washington, and also a small amount of storage in Salmon Lake, from which stored waters are released when needed into Conconully Reservoir.

The waters are diverted by a dam on Salmon River 12 miles below the reservoir, and conducted in canals and tunnels to lands in the valley of Okanogan River between Riverside and Okanogan, Washington.

The project is designed to irrigate 10,000 acres, but the water supply from the gravity system above described is not always sufficient for this purpose. To supply additional water in years of low run-off, a pumping plant has been provided to lift water from Okanogan River for the lower portion of the tract.

CONCONULLY RESERVOIR

This reservoir covers a small valley at the junction of the north and west forks of Salmon River, and covers an area of 460 acres, with a capacity of 13,000 acre-feet. The valley is narrowed at the dam site by a spur projecting from the west, leaving a gap of about 900 feet to be closed by the dam.

A low saddle in the spur is utilized as the location of a spillway.

Conconully Dam.— Borings were made at the dam site to a depth of about 60 feet, which indicated good material for the foundation of an earthen dam, consisting of a hard-packed mixture of sand, silt and clay under a surface of coarser sand and silt.

To prevent percolation through this surface material, a cut-off wall of sheet piling was driven 70 feet up-stream from the axis

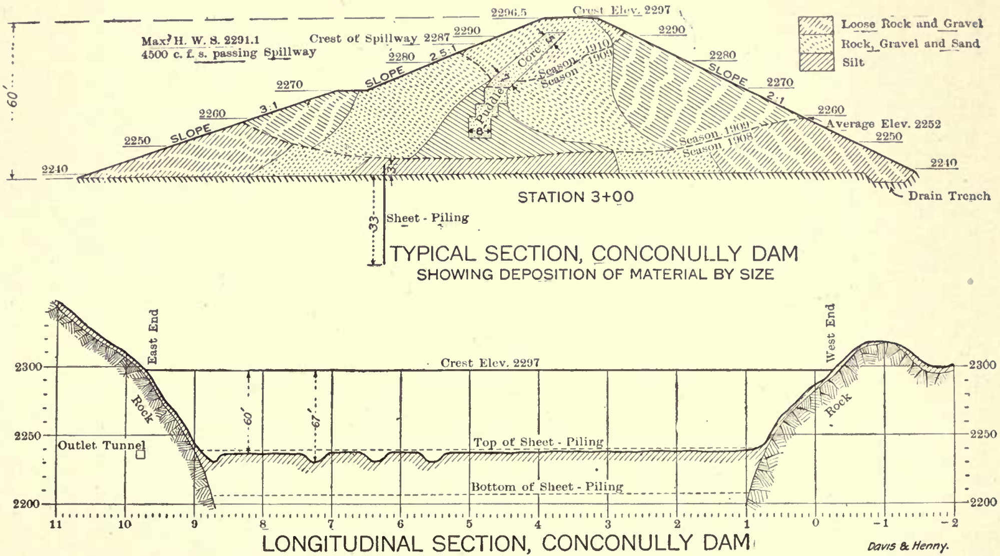


FIG. 106.—Sections of Conconully Dam, Salmon Creek, Okanogan Project, Washington.

of the dam, connecting with the cut-off trenches on the hillsides at the ends of the dam. The piling was built up of 2-inch tamarack plank, making each pile 6 inches thick. It extended about 33 feet into the ground, and projected 3 feet above, into the earth fill.

The height of the dam above the bed of Salmon River is 66 feet. Its top length is 1,010 feet, and bottom 815 feet. The down-stream slope is 2 to 1. The water slope varies from 3 to 1 at bottom, to 2½ to 1 near the top. The spillway provided has an overflow lip 180 feet long. The total volume of material in the dam is 351,000 cubic yards.

In considering methods of constructing the dam, the most prominent fact was the isolation of the locality. It was 105 miles from the nearest railroad point, Wenatchee, from which water transportation was available to a point 45 miles from the site, over poor mountain roads. Machine repairs could not be obtained nearer than Spokane, and very little local labor was available. These conditions imposed the necessity of utilizing local resources to their maximum extent.

It was found that abundant material was available on the west mountainside, just below the dam site, consisting of talus material grading from fine silt and sand through all sizes of angular stones to a cubic yard. This was examined by test pits and it appeared that it could be moved by the hydraulic process, and water under ample head could be obtained by diverting the west fork of Salmon River about 3 miles above, and bringing it in a flume to a point above the borrow pit. The excellent results obtainable with the sorting power of water upon such material as this was also a strong argument and the hydraulic method of construction was adopted.

The west fork of Salmon Creek, from which water was obtained, has a flow exceeding 50 second-feet from April 1 to July 1, and gradually declines to about 10 second-feet in August and September.

A flume of 17 second-feet capacity was built from the diversion point 3 miles along the mountainside to the borrow pit, which, after one season's use was enlarged to 26 second-feet, and to utilize this capacity in the late summer and fall, two small storage reservoirs were built on the two creek branches diverted to accumulate water during the night for use in daytime.

The flume delivered the water about 250 feet above the base of the dam.

Part of the water from 2 to 6 second-feet was delivered through pipes to hydraulic giants, one in each borrow pit, with nozzles changed from 2 to 3½ inches in diameter as required. A flow of from 2 to 3 second-feet was delivered to each flume under pressure from 114 to 170 feet through a 4-inch pipe to serve as push water. A portion of the remainder of the water was discharged free from the flume and ran down the mountainside, carrying material into the flumes, and the remainder was brought down in pipes and used as push water.

A large flume was built along the lower edge of the borrow pits and merged into a flume on a trestle reaching from the mountainside to the dam. At the dam the main flume was connected with two lateral flumes running near and parallel to the down-stream toe of the dam, and also to two lateral flumes near the up-stream toe.

When the dam was built up to these lateral flumes, the main trestle was raised 29 feet and lateral flumes were built nearer the center line of the dam, and these were fed from new flumes higher on the mountainside. When the dam was brought up to this second stage of fluming, a third stage was built, terminating in two laterals near the center line of the dam.

The main flumes along the mountainside were built the first season with slightly inclined sides, a depth of 2 feet and 3 inches, and a bottom of No. 10 mill steel curved to a radius of 1 foot. The erosion of the angular blocks carried by the water at high velocities soon wore large holes in the bottom of this curve, and a flat bottom 16 inches wide was then given the flume, which stood the wear much better. The flumes were given grades of 4 per cent for the first and second stages of trestle work and 3 per cent for the third stage or final finish of the dam. The short borrow-pit flumes, however, were given 3 per cent grades throughout the work.

In discharging the material upon the dam from the lateral flumes, a grating with 2-inch openings was placed diagonally in the flume, and the flume just above this grating opened on the side toward the outer edge of the dam and the coarse material deflected by the grating through this opening on the outer slope of the dam. Most of the finer material and water passed

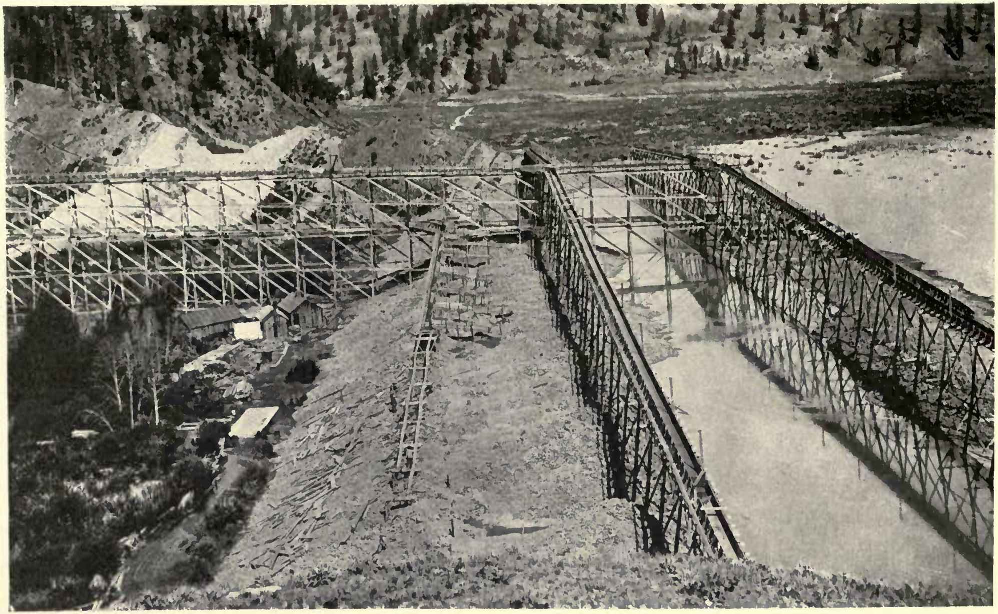


FIG. 107.—Trestles on Conconully Dam, showing Method of Hydraulic Construction.

at high velocity through the grating and was then discharged on the opposite side of the flume. The gravel fell in cones near the flume, the sand was carried farther and the water laden with fine sand and silt ran into the pond maintained in the center of the dam. In this way the material was roughly graded from coarse on both slopes of the dam to fine in the center.

A considerable amount of the material found in the borrow pits was large, rough boulders, too large to be washed through the flumes and was either broken small enough for water transportation or ejected from the pit. To get rid of such accumulated boulders, it was necessary to operate two pits alternately. The largest rocks carried by water were about 1¾ cubic feet in volume. The central pond was maintained at a depth of from 12 to 18 inches, and the surplus water drawn off on the reservoir side through flumes near the ends of the dam.

The waste water from the pond carried with it from 0.1 per cent to 0.5 per cent of silt, aggregating about 20,000 cubic yards in all, or about 5½ per cent of the material sluiced.

The pond at first was quite wide but as the dam increased in height it became rapidly narrower and, in spite of all efforts, the slopes of coarse material would extend so far into the pond as to leave insufficient puddle material between opposite slopes. Such places were broken up and fine material introduced, but gradually the narrowing embankment and the coarse material available ceased to furnish sufficient fine silt to form an adequate core, and it became necessary to secure loam from the valley floor for this purpose. This was hauled in scrapers to a platform above the east of the dam, and washed to place through an 8-inch pipe. Wooden forms were used to prevent the stratification of sand across this puddle core, which started considerably up-stream from the axis of the dam 14 feet above the valley floor, and sloped toward the center as it approached the top.

The coarse rock which formed the outer slopes was deposited so irregularly from the flumes as to require much handwork in finishing the slopes, but it was coarse enough to make excellent riprap, and no further protection of the slopes was required.

The material placed in the dam by the sluicing process measured in the pit about 330,000 cubic yards, and in the dam 340,000, showing an increase in volume due to segregation of sizes of about 3 per cent.

FIG. 108.—Conconully Dam and Spillway, Okanogan Project, Washington.

The coarseness of the material and the moderate grades available for the sluicing work made the percentage of material carried very low, and it decreased as the work progressed, owing to increased coarseness and decreased grades, notwithstanding the larger flow of water.

The relative effectiveness for the successive seasons is shown below:

Period	Hours Actually Sluiced	Hours Lost	Cubic Yards Sluiced	Average Yardage Per Hour	Average Water Supply	Average Percentage Material Carried
Apr. 22 to Oct. 15, 1908.	1,935	231	97,165	50.2	13.2	2.85
Apr. 14 to Nov. 13, 1909.	2,892	564	188,300	65.1	20.2	2.42
Mar. 31 to June 24, 1910.	1,154	297	64,900	55.4	22.3	1.87

The time lost, about 15 per cent, was due mostly to clogging of flumes by the large angular rock, to breaks in the feed flume and to repairs on the sluicing flumes. The largest output in a single day was 181 cubic yards per hour, when the water carried 5.3 per cent of solid material.

The resulting dam is an ideal structure for the purpose. The coarse rock of both slopes is proof against attacks of wind, rain, or waves, and has no tendency to slough or slide, and furnishes free and safe outlet for any leakage or seepage through the dam. The core of fine material furnishes the necessary water-tightness, having been thoroughly consolidated or packed by the treatment received.

Spillway.—The spillway provided was cut through the ridge forming the right abutment. The rock revealed was seamy and some of it soft. It was necessary to provide a concrete lip which was 180 feet long, and its lower slope was warped into a concrete channel passing through the ridge. Before the construction was undertaken a small spring was observed on the lower side of the ridge between the spillway and dam site, and close observation showed that its volume increased as the water was raised in the reservoir, and decreased as it was lowered again, the maximum discharge observed being about ½ second-foot. As the reservoir filled other springs appeared about the spillway, especially at the contact of the limestone with the underlying granite. The

total discharge of all these springs never exceeded 1 second-foot; it is entirely clear and inert, and involves no menace to the dam. As little water usually stands in the reservoir except during the irrigation season, the leakage involves no loss of water as it is diverted below for irrigation.

A small amount of seepage water appears in the flat below the dam, but whether this represents seepage through or under the dam is uncertain; it is probably the latter.

DISTRIBUTION

For drawing water from the reservoir, a tunnel 6×6 feet partly lined is provided in the granite abutment at the east end of the dam, through which the flow is controlled by two 36-inch gates set side by side, and operated through a tunnel up-stream from the axis of the dam. The normal discharge capacity is 100 cubic feet per second. This tunnel was employed during construction, before placing the gates, to discharge the flow of the stream, which it accomplished successfully.

The elevation of the outlet of Conconully Reservoir is 2,232 feet above-sea level. The stored water is drawn out as needed, and flows down Salmon River about 12 miles to the diversion weir which is at elevation 1,371, a fall of 861 feet. There are several points along this stream where topographic conditions are favorable for the development of power, but water would be available only in the irrigation season. The diversion dam is an ogee concrete structure with 50-foot length of overflow, which raises the water 4½ feet into a canal with a capacity of 110 cubic feet per second.

Two miles below the head of the canal about 50 second-feet of water is dropped 110 feet to a lower bench, and two miles further down the upper canal another drop of 58 feet occurs. These drops are used for developing power used for pumping on about 1,070 acres of the lower lands. The water thus pumped is lifted from the Okanogan River and thus supplements the supply available from the Salmon River. Each of these power-plants develops 187 kilowatts on the switchboard, which is transmitted about 5 miles to the pumping plant near Omak, to lift water to about 1,070 acres on Robinson Flat. The pumping plant and both power-plants are installed in reinforced concrete buildings

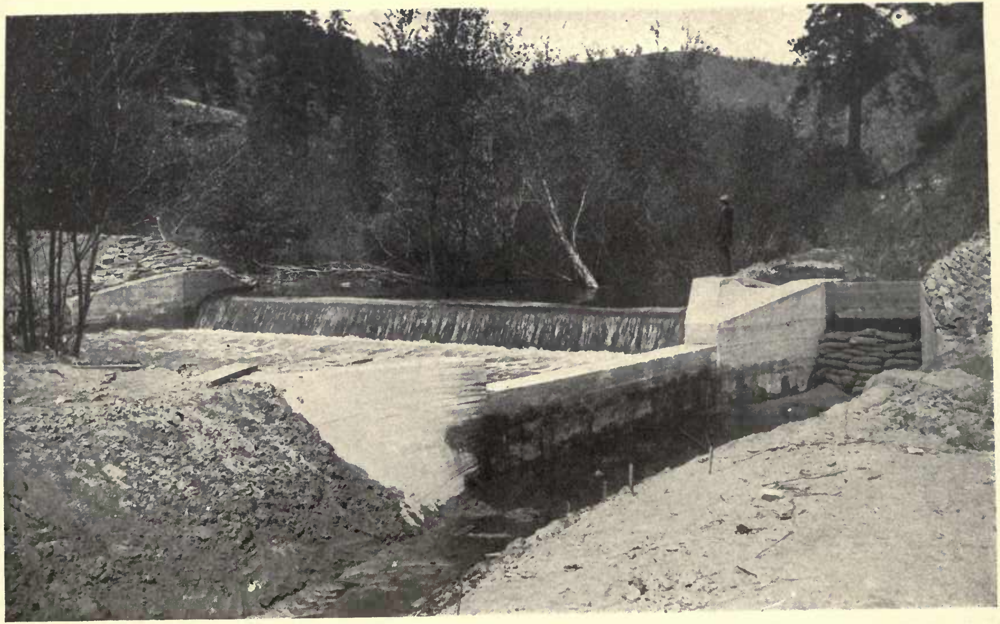


Fig. 109.—Salmon River Diversion Weir, Okanogan Project.

with roofs of corrugated galvanized iron. Power-plant No. 1 uses 27 second-feet under a head of 105 feet, through a turbine wheel developing about 250 horse-power, direct connected to the 187-kilowatt generator.

The penstock is a 26-inch steel pipe and is 313 feet long.

Power-plant No. 2 takes 55 second-feet of water under 56 feet head, through a 40-inch pipe 154 feet long developing nearly 300 horse-power on a turbine wheel and 187 kilowatts on the switchboard. Both wheels are controlled by automatic governors and are provided with relief valves.

The current is generated at 6,600 volts and transmitted 5⅓ miles to the pumping plant, where it is transformed to 2,200 volts.

The pumping plant has two units alike. Each consists of a 200-horse-power induction motor, direct connected to a two-stage centrifugal pump of 6-second-feet capacity.

The switches are as nearly automatic as possible, automatically starting and stopping the motors in case of shutdown.

The two pumps unite their 12-inch discharge pipes in a "Y," which increases to 30 inches and is built of steel for 225 feet, to a bench 114 feet above the river. Here it connects with a 30-inch continuous wood-stave pipe 4,117 feet long. The total lift is 177 feet. The pumping plant is arranged so that one unit may be run with one power-plant at full or partial load, or both units may be run at full load or less. The wood-stave pipe is used as part of the gravity system when the pumping plant is not used. The capacity of the plant is about 12 second-feet, it serves about 1,070 acres, and cost about $62,000.

The pumping plant is purely for a supplementary supply, and will be used only in case of insufficient supply in the reservoir. It will be idle more seasons than it is used, but is indispensable in low-water years.

A part of the main canal through rock is lined with concrete for the purpose of economizing in excavation and for preventing percolation. A large part of the distribution system also is lined, the portions selected for this being those located in sandy reaches where the seepages loss would be great without the lining.

Water is delivered on a rotation system of seven-day intervals, which economizes water and also the time of the individual irrigator. It also affords opportunities for cleaning ditches and for killing weeds and aquatic plants.

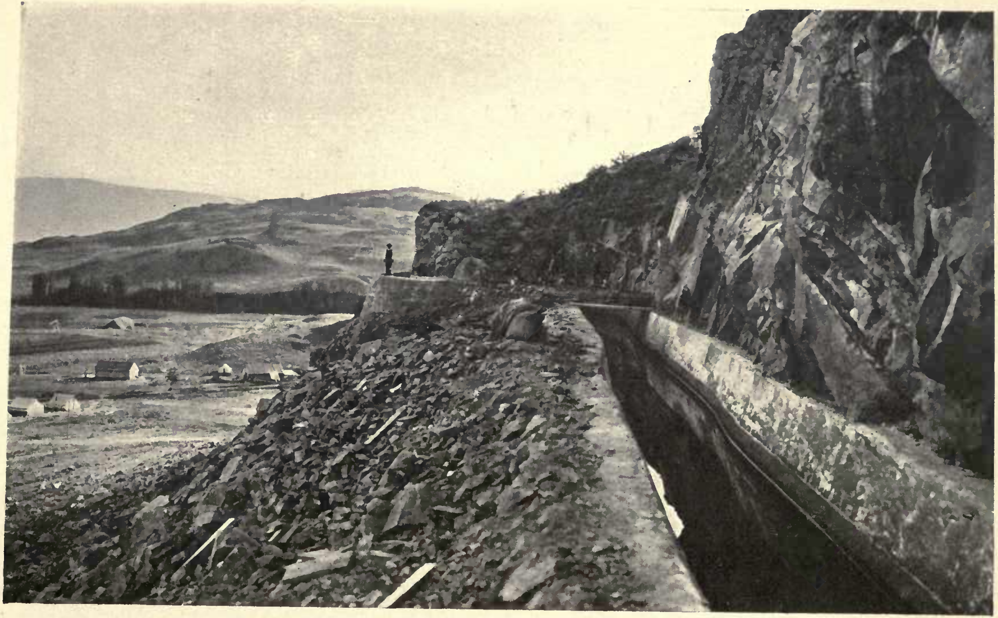


FIG. 110.—Main Canal, Concrete Lined, Okanogan Project, Washington.

FIG. 111.—General View of Orchards on Okanogan Project.

WATER DELIVERY

The rotation method of delivery of water is employed on the Okanogan Project, the system being to allow a water user for one week double the amount of water which would be required for constant flow and then one week without any water delivery.

This schedule is worked out before the irrigation season begins and each water user is notified of the dates on which he will receive water. The schedule is adhered to as nearly as practicable, but numerous modifications are made to accommodate the irrigators.

The system as worked has been found reasonably economical of water and of labor, and is entirely satisfactory to the water users.

The major portion of the land irrigated under the Okanogan Project is planted to fruit trees, the apple, peach, and pear being the principal fruits grown. The climate and soil appear to be well adapted to success in this industry, and the future of the project is bright.

Conconully Dam was built by Lars Bersvik under the direction of E. G. Hopson. The canal system was built by Ferd Bonstedt. D. C. Henny as Supervising Engineer was mainly responsible for the plans and the work of the project.

CHAPTER XXI

YAKIMA PROJECT, WASHINGTON

GENERAL STATEMENT

The Yakima Project is situated in the southeastern portion of the State of Washington, in the valley of the Yakima River, a tributary of the Columbia River, having its source in the Cascade Mountains. The Yakima River has a length of about 175 miles; the drainage area is 5,270 miles, and the mean annual run-off is about 3,300,000 acre-feet. The elevation of the irrigable area is about 400 feet at the lower end of the valley, and about 1,600 feet at the upper end, and the rainfall varies from about 6 inches at the lower end to 11 inches at the upper end. The soil is, in general, volcanic ash or a sandy loam, of considerable depth, the lower lands and those bordering the river being underlaid with a gravelly sub-soil.

The first irrigation in the Yakima Valley was undertaken by private parties in 1867, and in 1903, when the Reclamation Service made its first investigation of the valley at the request of the landholders, there were approximately 120,000 acres under irrigation by private enterprise. The total area of tillable land that can be irrigated from the Yakima River and its tributaries, supplemented by storage reservoirs, is estimated at 670,000 acres, of which about 300,000 acres have been provided for by systems, Government and private, completed or nearly completed, and 370,000 acres are still undeveloped.

Water Rights.—In 1903, when the Reclamation Service entered the valley, there were about 120,000 acres under irrigation, there was no system of regulating the diversions, all the natural flow had been appropriated, and the appropriations far exceeded the available supply, and it was urgently necessary that a check be placed on further appropriations and that the existing appropriations be limited to the quantities actually used.

This was the first problem requiring solution by the Reclamation engineers. They were assisted in this by the great interest

taken therein by the people of the valley, and the efforts resulted in the signing of agreements by all the important water appropriators, which limited their rights to specific quantities, based on the quantities diverted during the month of August, 1905.

The situation in 1905 was such that all further development required the storage of flood waters, and it was with a full understanding of this condition that development was undertaken by the Reclamation Service. A special act of the State legislature granted to the United States certain rights of way and water rights that enable it to carry on its operations without hindrance with the view of ultimately developing the complete water resources of the Yakima Valley.

Storage Reservoirs.—There are five principal reservoir sites, three at the headwaters of the Yakima River and two at the headwaters of its principal tributary, the Naches, that are considered feasible at the present time. There are several other sites that are feasible as far as water supply is concerned but that at the present stage of irrigation development are considered too expensive to warrant serious consideration. The five reservoirs mentioned and their capacities are as follows:

Reservoir	Capacity, Acre-Feet
Kachess	210,000
Keechelus	152,000
Clealum	501,000
Bumping Lake	34,000
Tieton	185,000
Total	1,082,000

The combined storage capacity of these reservoirs when fully developed, as at present planned, together with the natural flow of the river, will assure a sufficient supply of water for about 670,000 acres.

There are at present completed the Bumping Lake and the Lake Kachess Reservoirs. The Lake Keechelus Reservoir is nearly completed. At Lake Clealum a low crib dam affords a small quantity of storage. No construction work has been done on the Tieton Reservoir.

Units of the Yakima Project.—The topographical features and

economy of construction have divided the valley into a number of units, which, except for those already developed, may or may not be ultimately developed in the form and size at present outlined. These units and their areas are as follows:

Unit	Area, Acres
Kittitas	82,000
Tieton	34,700
Wapato	120,000
Sunnyside	102,000
Benton	90,000
High Line	100,000
Total	528,700
Under existing private projects, about	140,000
Total irrigable area of the valley	668,700

The Tieton Unit is completed and the Sunnyside Unit is nearly completed. The Indian Service is now irrigating about 40,000 acres under the Wapato Unit. The Kittitas Unit is now in private hands under the State Irrigation District Law, and contemplates obtaining stored water from the Government under the Warren Act. No definite steps have been taken toward the development of the Benton and High Line Units. The location of these units as well as the storage sites above mentioned are shown on the accompanying map of the Yakima Basin.

BUMPING LAKE DAM

This is an earth dam located at the outlet of Bumping Lake, near the headwaters of the Bumping River, a tributary of the Naches, which, in turn, flows into the Yakima River, near the city of North Yakima, about 60 miles away. The capacity of the reservoir is 34,000 acre-feet; the area at high water is 1,350 acres and the drainage area of the basin above the dam is 68 square miles. The dam is an earth fill with puddled core and its principal features are given in the following tabulation:

Maximum height above stream bed, 45 feet.
Length of crest, 3,425 feet.
Top width, 20 feet
Slopes—down-stream, 2 to 1; up-stream, 3 to 1.

Volume, 233,850 cubic yards.

Spillway length, 235 feet.

Crest of spillway, 9 feet below crest of dam.

Capacity of spillway, 6,000 c.f.s.

Outlet gates, 2 × 5′—5′ C. I. slide gates for regulation, protected by a similar pair of emergency gates.

Low-water capacity of outlet gates, 500 c.f.s.

Fig. 112 shows the maximum cross-section of the dam as constructed.

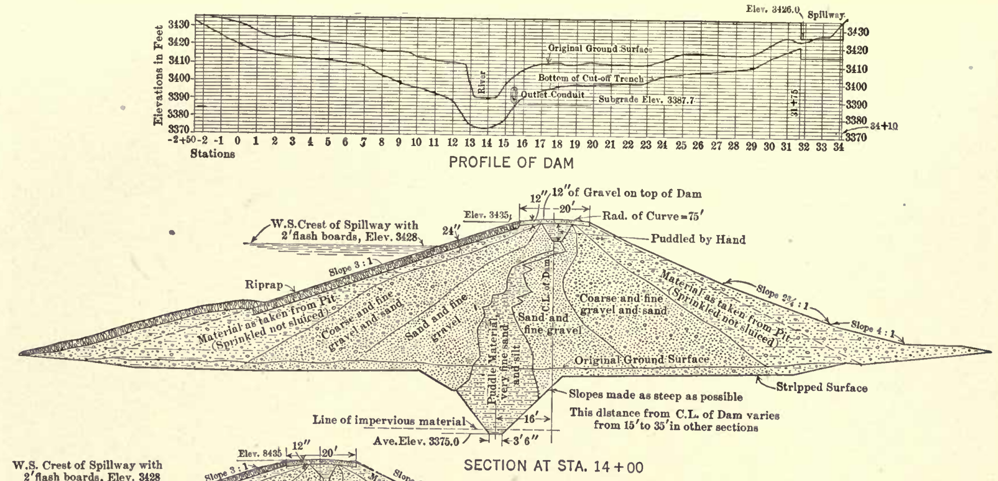
The construction of the dam was advertised twice for bids, but none were received, probably due to the fact that the work was located more than 60 miles from North Yakima, the nearest supply point, in extremely rough country and with the nearest railroad station at Naches City 47 miles by wagon road from the dam site. The dam was consequently authorized for construction on November 19, 1908, by force account.

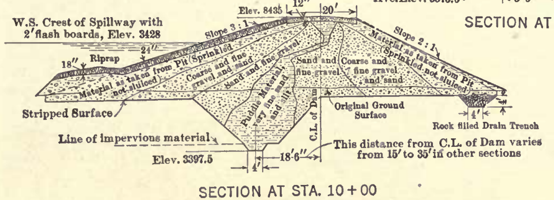
Wagon Road.—One of the principal features connected with the construction of the Bumping Lake Dam was the wagon road 47 miles in length from Naches City to the dam site. This road follows the Naches and Bumping Rivers and included the construction of several bridges, heavy rock and earth cuts, and considerable cribbing and corduroy work as well as many difficult construction features.

Construction of the Dam.—Construction operations at the dam were started in May, 1909. By the end of June, the clearing and grubbing of the dam site were completed and stripping begun. Water was brought from a stream about 4,000 feet from the south end of the dam by a canal and flume into a penstock near the south end of the dam, which water supplied the camp boilers and was used for sluicing.

A 45-ton Bucyrus steam shovel and a 1-cubic-yard Hayward orange-peel skid excavator, together with teams and scrapers, were the principal items of excavating equipment.

The embankment material was excavated from the borrow pit by steam shovel and loaded into 1½-cubic-yard dump cars, which were hauled by horses on a track placed on the outer edges of the embankment slope. The cars were dumped toward the center of the dam and water under pressure was used to sluice the finer material toward the center, where a settling pond was maintained to make an even, compact puddle core. By this





ESTIMATE OF QUANTITIES BODY OF DAM	
ITEM	AMOUNT
Clearing and Grubbing	14.93 acres
Stripping (dry)	15,743 c.y.
Excavation (dry)	29,912 c.y.
Excavation (wet)	5,273 c.y.
Embankment	233,852 c.y.
Rock-fill at Toe of Dam	2,700 c.y.
Riprap, upper slope	11,190 c.y.

FIG. 112.—Profile and Sections of Bumping Lake Dam, Yakima Project, Washington.

sluicing process the heavier gravel and boulders were left to form the outer portions of the dam. The tracks were shifted as the embankment was raised and the core thus became progressively thinner. This also gave the proper slope to the faces of the dam. The larger boulders from the sluiced materials were placed on the reservoir side of the embankment, and these, together with a large quantity of rock obtained from the spillway excavation, were made to form a 2-foot thick riprap face for the embankment.

It was originally intended to construct the embankment in the ordinary manner by depositing the material in layers with the usual distribution of fine and coarse material and by spreading, wetting, and rolling, but on account of the unsatisfactory foundation conditions and the presence in the material of a large percentage of cobbles and large boulders that could not be satisfactorily rolled, and that would be impracticable to remove by hand, an entire change of method was necessary.

The material encountered in the cut-off trench was not as tight and firm as expected and excavation had to be carried deeper than originally contemplated. Serious seepage conditions were encountered in the lower portion of the trench; the layer of hardpan that it was expected would give a practically impervious foundation was underlaid by a stratum of loose gravel and coarse sand. This condition required radical changes in the plans of construction and the principal change decided upon was to puddle thoroughly the material in the cut-off trench and to effect a separation of the materials in the embankment by hauling out on the dam with cars, dumping the material near the outer edges of the embankment, and sluicing into place.

Water from the mountain streams beyond the north end of the dam was brought by gravity to the dam in sufficient quantity for effective work. A line of 12-inch wood-stave pipe was laid across the spillway approach in a trench dug to subgrade to the north end of the dam, where it branched into two lines of 6-inch wood pipe, one line laid along the bottom of each slope of the dam. At intervals of from 100 to 150 feet, 2-inch wrought-iron nipples with 2-inch valves opening toward the embankment were screwed into the 6-inch pipe. For sluicing purposes, 2-inch cotton hose in 50-foot lengths and ¾-inch nozzles were used. By this arrangement, water could always be readily obtained at

FIG. 113.—Spillway, Bumping Lake Dam, Yakima Project.

different sluicing points, and any hose-line could be changed without interfering with others. The pressure head at the top of the dam was about 70 feet.

The steam shovel and borrow pits were located near the south end of the dam and it was necessary to build temporary trestles to carry the material across the river so that filling of the northerly portion could be in progress while the river section was being prepared. This trestle was 490 feet long and had a maximum height of 35 feet with bents spaced 20 feet apart. The double track was laid directly on the floor, which was 14 feet wide, but it was found that with the tracks so close to the edges the horses and mules would crowd toward the center, making it impracticable to have trains pass on the bridge.

A large quantity of material was dumped down-stream from the high trestle. An opening, sufficient to allow the escape of water pumped from the cut-off trench, was left near the south end. When the excavation of this trench was completed, this opening was filled and when the dump thus made had become sufficiently high, the tracks were removed from the trestle to the embankment, and the trestle, with the exception of a few posts that were cut off as low as possible, was taken out. The material was then dumped from this road-bed and sluiced into the trench. The track on the opposite slope was worked at the same time, the material also being sluiced into the trench.

While working on the embankment at the higher levels, it was necessary to use a series of settling ponds. These ponds varied in length from 200 to 400 feet, and were separated by small earth dams carefully made of selected material which was wetted and thoroughly compacted. When these dams attained considerable height, they were difficult to maintain and occasionally broke through, but when a continuous pond was obtained this trouble was obviated and the embankment was more easily carried. Great care, however, had to be taken to keep a satisfactory width and depth to the pond. The size and shape of the pond were regulated by changing the dumping place and method of sluicing, as necessary. When the slope became too flat, it was steepened by reducing the force of the sluicing.

A satisfactory silt core was obtained to about spillway level, but above this, on account of the narrow pond, the method had to be changed. The method subsequently used was to dump

the material in shallow ponds and work it with shovels to prevent stratification.

Outlet Works.—Water is drawn from the reservoir through a 7-foot reinforced concrete conduit near the middle of the embankment. The outflow is controlled by two sets of 5 × 5 cast-iron slide gates having two such gates in each set, one to be used for regulation and the other for emergency use. The gates are operated by hand from a concrete tower, access to the tower from the crest of the dam being had by a light steel foot-bridge.

Spillway.—The spillway weir having a length of 235 feet is located at end of the dam. The crest of the spillway is 9 feet below the crest of the dam, and the spillway has a capacity of 6,000 second-feet. The spillway channel reduces in a length of about 200 feet to a 42-foot wide concrete channel 150 feet long with side walls 10 feet high. At the end of the concrete channel is a wooden flume 42 feet in width and 100 feet long on concrete piers. This flume discharges the flood water into the Bumping River below the dam.

KACHESS DAM

Description.—The Kachess Dam is a rolled earth fill. It is located at the lower end of Lake Kachess about 3 miles from the town of Easton on the Northern Pacific Railroad, and about 100 miles from the city of North Yakima. Lake Kachess is the middle one of the three large lakes near the head-waters of the Yakima River in the Cascade Mountains. It has a very regular shape, is about 10 miles long, and has a maximum width of about 1 mile. It discharges into the Kachess River, which, in turn, flows into the Yakima about 2 miles below the outlet of the lake. The capacity of the reservoir is 210,000 acre-feet. The area of water surface at high water is 4,800 acres, and the area of the drainage basin above the dam is 63 square miles. The maximum run-off has been about 277,000 acre-feet and the average run-off for a period of eight years was 209,000 acre-feet.

The essential details of the dam are shown in the following tabulation:

Maximum height above stream-bed, 63 feet.
Length at crest, 1,400 feet.
Top width, 20 feet.
Slopes—down-stream, 2 to 1; up-stream, 3 to 1.

Volume of embankment, 182,000 cubic yards.
Length of spillway, 250 feet
Crest of spillway, 10 feet below crest of dam.
Capacity of spillway, 7,200 c.f.s.
Outlet gates—3–4′ × 10′ for regulation .
3–4′ × 10′ for emergency use.
Normal capacity of outlet, 1,000 c.f.s.

The Kachess River is very crooked. In a distance of 2 miles it progresses only 2,800 feet in a straight line from the lake. The river drops some 35 feet in this distance. The irregular course of the river afforded excellent facilities for handling it during the construction and the depth of the lake and large fall of the river within a short distance made feasible the tapping of the lake at an elevation about 30 feet below its normal outlet, thereby giving 76,000 acre-feet of storage below the elevation of the natural outlet of the lake.

The dam is built across the Kachess River about 1,800 feet below the most southerly point of the lake. It is of the earth and gravel type 65 feet high and 1,400 feet long. Its crest is at elevation 2,268, and has a top width of 20 feet. The up-stream slope of the dam is 3 to 1, and the down-stream slope 2 to 1. To prevent percolation, a wide cut-off trench about 20 feet deep was excavated parallel with the axis of the dam and from 20 to 60 feet up-stream from the center line. In the bottom of this trench a narrower trench was excavated to a depth of from 35 to 75 feet below the original ground surface, and in it a concrete core-wall 2 feet thick was built extending up to the original surface of the ground.

The outlet channel consists of five distinct sections: An open channel extending out to deep water in the lake, followed by a closed conduit through two bends in the original course of the river, an open channel crossing the old river-bed, a closed conduit through the dam, and finally a paved open channel discharging into the river.

The first section of the outlet channel is an open channel about 1,200 feet long extending from deep water in the lake to a point where a covered conduit was found to be more economical. This conduit is of reinforced concrete about 1,400 feet long, horseshoe shape, 9 × 10 feet in cross-section. This diverges into a paved open channel of large cross-section and about 300 feet

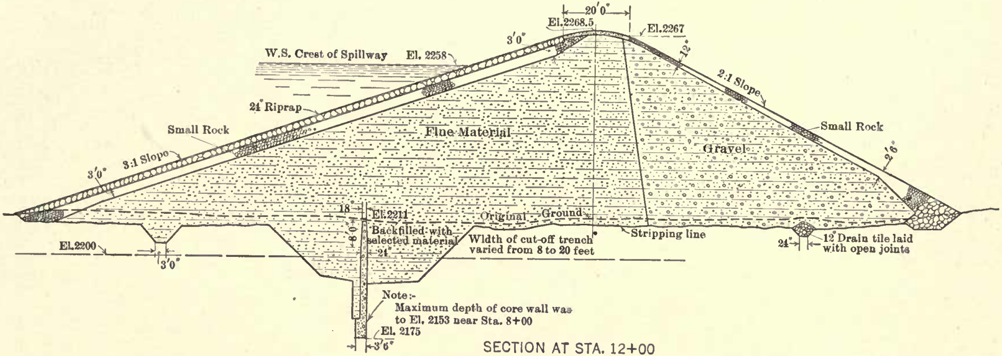


Fig. 114.—Section of Kachess Dam, Yakima Project, Washington.

long immediately in front of the dam. The conduit through the dam is of reinforced concrete, horseshoe shape, 12 × 12 feet in cross-section and 300 feet long. It discharges into a paved, open channel about 500 feet long which empties into the Kachess River. The flow is controlled by three sets of two cast-iron slide gates, each 4 × 10 feet, placed at the intake of the dam conduit and operated by power from the gate towers. The maximum capacity of the outlet works is 5,000 cubic feet per second at high water, but at low water is intended to have a capacity of only 400 cubic feet per second, while the normal designed capacity is 1,000 second-feet.

The spillway which is constructed at a low point in the rim of the reservoir ½ mile east of the dam has a crest length of 250 feet, and is designed to discharge 7,200 second feet, with a head on the weir of 4 feet. Provision has been made for placing 2 feet of flash-boards on the crest of this weir to get additional storage capacity.

Construction of the Dam.—The construction of the dam was authorized in February, 1910, and some work was done by Government forces in the following few months. In the spring of the same year, bids were asked for the construction of the dam, but the proposals received were considered too high and rejected. The entire work was subsequently done by force account.

The dredged channel from deep water in the lake is about 1,000 feet long. Its bottom is from 30 to 35 feet below normal water surface, and the depth of excavation averaged about 27 feet. It has a bottom width of 12 feet and side slopes of 3 to 1. The material was a blue clay, soft and oozy on top and gradually growing dryer and harder with the depth. The total volume removed by dredging was 105,000 cubic yards. In fair digging, the output for an eight-hour day was 500 cubic yards, the maximum being 630 cubic yards. The output was at times erratic on account of high winds and rough water or the necessity of working against a strong current when releasing storage water. An orange-peel bucket was used for dredging.

The intake and trench for the conduit, from the lake to the open channel in front of the dam, were practically all excavated with a drag-line excavator. The intake excavation was difficult, as the material at the lake end and sides was mainly a plastic blue clay similar to that in the lake-bed, and was removed during the

rainy season. It was intended to carry a portion of the excavation on a 2 to 1 slope, but on account of the oozy material and wet weather much of it assumed a much flatter slope, and at times it was difficult to prevent the machine from sliding with it. At the intake where concrete was to be placed it was necessary to put in considerable heavy crib-work to hold the material. The grade of the intake is 36 feet below the lake level, and water came in so freely that an 8-inch centrifugal pump was kept going continuously to handle it. The soft material gave out a short distance from the lake. In digging the trench, the excavator was kept on the center line digging from the end and dumping to either side; the cut was from 30 to 55 feet deep; the trench was taken out to a bottom width of about 15 feet with slopes as steep as they would stand. The material was a cemented gravel containing a comparatively small amount of clay but so firmly cemented that in places its sides would stand almost vertical, even with the water dripping over them, and so hard that it was necessary to loosen the entire cut by blasting. The length of this trench was 1,400 feet, and it involved the excavation of 85,000 cubic yards of material. The remainder of the intake channel, consisting of 300 feet of open channel, from the end of the trench just discussed to the dam was excavated partly by the drag-line excavator and the deeper canal by the steam shovel.

The excavation for the conduit under the dam and for the open channel below the dam was started with teams, but it was subsequently found that the material was so hard and stony that it was necessary to excavate it with a steam shovel. The bottom of the channel was as narrow as 15 feet in places and the maximum cut was 35 feet with 1½ to 1 slope, and it was necessary to make five separate cuts.

The wide cut-off trench under the dam was excavated with teams and drag-line excavator, the former being used for the dry material and the latter where water was encountered. The drag-line excavator deposited the material at the up-stream toe of the dam, making an excellent footing for the riprap and also disposing of the material with one handling.

It was the original intention to carry the concrete core-wall trench to bed-rock, but the entire excavation was in such uniformly good material that it was considered unnecessary to go so deep. The maximum depth reached was near the westerly

end, which was carried to a depth of 75 feet below the original ground surface.

Concreting followed closely on the completion of the excavation work. Owing to the cramped and wet quarters in which the conduit in the approach to the dam was built, the work had to be prosecuted day and night in order to complete it in the required time, which time was limited by the requirement for the passage of irrigation water. The conduit under the dam was surrounded at frequent intervals by cut-off walls projecting 4 feet on all sides of the conduit.

The construction of the lower concrete work was followed by the construction of the gate tower. This tower consists of three sets of three compartments each. The up-stream compartments contain the emergency gates, the down-stream compartments contain stop-plank grooves, while the interior compartments contain the regulating gates. The operating mechanism installed on the floor of the gate-house is so arranged that the gates can be operated either by hand or by power. Power is obtained from a small turbine installed in the west stop-plank compartment. To prevent drift from reaching the gates, an ample grillage of structural steel is provided; it has an effective area of 1,200 square feet, or ten times the area of the gates, and extends from the floor of the intake to a point 4 feet above the spillway level. The gate-house is 15 × 23 feet in plan. Access to the gate-house from the dam is had by means of a steel foot-bridge, 161 feet long, supported on three steel bents.

Embankment.—The preliminary investigations for borrow pits indicated that there were two places from which tight material could be obtained. One of these was located within 1,000 feet of the east end of the dam, while the other was about 1,500 feet from the west end. The subgrade of the easterly pit was at the same elevation as the crest of the dam, while that of the westerly pit was about 20 feet below it. The former was the more favorable from every standpoint, and consequently was selected. There was no choice in the location of a pit for coarse material, as the only material of this kind suitable for the work was found at a distance of some 2,500 feet from the east end of the dam.

The material in the borrow pit proved a good deal better than tests indicated. The upper 3 feet consisted of top soil, light in weight and containing a large amount of fine earthy material,

and, with the exception of scattered boulders of large size, the layer contained about 50 per cent of the boulders found in the pit. Below this hard-pan was found consisting of clay, sand, and from 35 to 40 per cent of coarse and fine gravel. This layer was so hard as to require shooting, but the material below, although it contained about the same ingredients and possibly a larger percentage of clay, was not so firmly cemented.

The embankment was compacted by the sprinkling and rolling method. The material was spread in 8-inch layers and all stones exceeding 4 inches in diameter picked out, loaded into one-horse dump carts, and placed on the up-stream slope for protection against wave action. The trestle from which the material was dumped was 800 feet long, of which 300 feet averaged 60 feet high. It was built of round timber saved from the clearing, except the caps and stringers, which were dressed. The bents were 20 feet apart, three posts to a bent. The trestle was located practically on the center line of the dam with the base of rail at the proposed crest. It was double-tracked with 30-pound steel rails, 24-inch gage. A double track was laid to the borrow pit for tight material and a single track, with sufficient turnouts, to the borrow pit for loose material.

The material from the borrow pit was loaded into trains of 15 1½ cubic-yard side-dump cars, hauled by 9-ton steam locomotives, and was dumped from the up-stream side of the trestle. Spreading was done with four-horse fresnoes. It was found, after the work became systematized, that one fresno would distribute about 150 cubic yards of the tight material in eight hours. The gravel or loose material was loaded by the drag-line excavator into a specially constructed hopper of 40 cubic yards capacity, mounted on skids for moving, and fitted with two chutes and controlling gates, which enabled two cars to be loaded at one time. It was hauled in trains of twelve cars each, dumped from the down-stream side of the trestle and spread with four-horse fresnoes. One fresno would spread from 150 to 175 cubic yards of gravel in eight hours, the haul being much shorter than for the tight material and the gravel more easily loaded.

On account of the small working space of the embankment, difficulty was at first experienced in spreading the material as fast as it came in, but, while the capacity of the machines was never taxed, a system was soon devised whereby it was kept

pretty well cleaned up. About ten trains would be dumped in one pile; then another pile of ten train-loads would be made near the first pile, leaving only room for a roadway between; then a third pile adjacent to the second. While the second pile was being made the first pile would be spread and stones picked from the second pile; then while cars were dumping on the third pile, the stones would be picked from it, and the second pile spread. In this way there were no waiting and no confusion with the roller working on the area previously spread. The tight material occupied the up-stream two-thirds of the dam and the gravel the down-stream one-third. The gravel was handled in the same way except that it spread much easier and the piles did not require plowing, which was necessary with the tight material. The impact from falling, particularly in the lower levels of the embankment, compacted this material very tightly.

The tight material was spread in 8-inch layers and sprinkled by a 2-inch hose with $\frac{3}{4}$-inch nozzle, the amount of water varying greatly and depending on the weather and material. The tendency at first was to use too much water, which produced a kneading motion in front of the roller. Careful watching of the conditions and reducing the amount of water, and sprinkling often with a rather fine spray, corrected this condition. The rolling was done with an ordinary $16\frac{1}{2}$-ton traction engine. Extension rims on the driving wheels gave a rear-wheel base of 56 inches. Assuming that they carried two-thirds of the weight, the pressure per linear inch was 400 pounds. This engine seemed about the right weight for the material, and an excellent embankment was obtained.

It was found that the compacted layer was slightly less than 6 inches in thickness. Test pits were put down frequently in order to have a complete record of the behavior of the material, to determine whether or not the proper amount of water was being used, and, in general, to indicate whether there was anything to be guarded against or improved. No stratification was apparent, the only adverse criticism to be made was that certain layers that had been exposed to rain showed a little too much water. The gravel was spread in a similar manner except that small stones were not so carefully picked out. The rolling was done by a grooved roller drawn by four horses and more water was used than on the upper side. The stones picked out were

placed on the down-stream slope. The junction of loose and tight material in the dam was approximately at the down-stream post of the trestle bent.

All trestle bracing was taken out as the fill was raised, nothing being left in but the posts. When within 8 feet of the top the gravel portion was brought up about 6 feet, one track thrown on it, the balance of the trestle removed, and the remainder of the embankment completed.

An analysis of the material for the tight portion of the embankment as determined from samples taken at different depths from the borrow pit gives the following percentages passing through different screens:

Screen No.	Per Cent Passing	Screen No.	Per Cent Passing
3/4	98.3	20	38.3
4/5	94.7	40	31.3
1	91.6	60	26.1
1 1/3	83.6	80	23.3
2	74.9	100	21.3
3	68.9	165	18.0
4	60.3	200	16.7
10	47.3		

A very complete drainage system was provided in the dam to lead off harmlessly any water that may find its way into the dam. At the down-stream toe is a large trench from 6 to 10 feet wide in the bottom and from 6 to 8 feet deep extending the entire length of the dam and backfilled with stone, which filling is also carried some distance up the slope. From 30 to 60 feet up-stream from the toe is a 12-inch tile drain laid with open joints in a trench and surrounded with 2 feet of small stone. This drain has frequent outlets to the main drain at the toe. Should water succeed in passing through the tight material, it will drop in the gravel portion, which contains practically no clay, and escape through the drain.

The up-stream slope of the dam is protected from wave action by a 2-foot layer of riprap placed on a bed of small stone 3 feet thick, thus making a thickness of 5 feet of rock between the embankment material and the water. The smaller stones are generally against the embankment, while the outer stones are

practically all 2 feet thick, many of them being of derrick size. The down-stream slope requires no protection, but to prevent ravelling and to better hold the material it was faced with a layer of small stone picked out of the loose material. This layer is thicker at the bottom than at the top and averages about 3 feet.

The principal items included in the construction of the dam were as follows:

Clearing	50 acres
Grubbing	16 "
Excavation	550,000 cu. yds.
Concrete	8,635 "
Dry paving, 12″ thick	1,600 "
Grouted paving, 12″ and 18″ thick	1,250 "
Gravel under dry paving	625 "
Backfill	320,000 "
Rockfill	2,700 "
Riprap	8,500 cu. yds.
Embankment	182,000 "
Drain pipe, 12″	900 lin. ft.
Drain pipe, 8″	100 "
Reinforcing steel	300,000 lbs.

TIETON UNIT

The Tieton Unit comprises about 34,000 acres of land, the main body of which lies directly west of the City of North Yakima and approaches practically to the city limits. Much of the land in the immediate vicinity of North Yakima is irrigated by privately owned ditches taking water from the Naches River and neighboring streams, but these ditches water only the lower-lying land, the lands included under the Tieton Project being higher in elevation. The project thus borders on a highly developed district, agriculturally, and a fast growing one, and in that respect is very favorably situated.

The irrigation system of the Tieton Project was difficult to construct on account of the necessity of having to carry the main supply canal down the deep canyon of the Tieton River for a distance of 12 miles, involving the construction of a lined canal on a very steep side hill several hundred feet above the river-bed, and requiring several tunnels aggregating in length about 11,000 feet.

Water is diverted from the Tieton River into the main canal

at a point about 16 miles from the mouth of the river, and about 36 miles from the City of North Yakima. The principal features of construction are listed in the following tabulation:

Diversion dam and head-gates.

9.8 miles of segmental concrete-lined canal 8′ 4″ in diameter with the sides extending about 2 feet above the horizontal diameter.

Six tunnels aggregating 10,963 feet in length.

Five automatic wasteways for protecting the main canal by discharging the water from the canal in case of accident.

32 miles of canal from 50 to 300 second-feet capacity.

193 miles of canal less than 50 second-feet capacity.

533 concrete and wooden canal structures of various sizes.

279,000 feet of concrete, wood and clay pipe of various sizes.

77,400 feet of wood and metal flumes.

Excavation of about 1,500,000 cubic yards of material of various classes.

Wagon Road.—Preliminary to the construction of the main canal in the Tieton Canyon it was necessary to build a road from the mouth of the Tieton River to the head-works. This involved the construction of about 15 miles of road, including several bridges across the river.

Diversion Works.—The diversion works consist of a reinforced concrete intake structure and a low crib and concrete dam. The intake structure has three 4 × 5 gate openings controlled by cast-iron sluice-gates with rising stem and independent hand gears. The elevation of the gate still is 2,295.14 feet above sea-level, and the operating floor is 18 feet higher. The maximum high water in the river is estimated to be at an elevation of about 3½ feet below the operating floor. The designed capacity of the main canal is 300 cubic feet per second and the gates are designed to pass this quantity at the low-water stage of the river. The gates are protected by flash-board grooves, both above and below, so that one gate may be cut out of service and removed at any time without interference with the others.

The diversion dam is a simple structure, having a concrete rollway 3 feet high and 110 feet long with its crest about 12 feet below the operating floor of the intake structure. The intake structure is protected on the up-stream side by sheeting, and well puddled, and on the down-stream side by a timber crib 16 feet wide constructed of logs drift-bolted together and faced with 6 × 12 timbers. Protection from back-cutting is given by 6 × 12-

inch sheeting extended downward vertically to impervious material and the filling in the river-bed beyond with large-size boulders. To avoid the deposition of gravel in front of the gates, two sluiceways 6 feet wide are provided through the dam at the end immediately adjacent to the head-gates. The floor of these sluiceways is 3 feet below the crest of the spillway, and at times of extreme low water these gates may be closed by dropping flash-boards in grooves provided for the purpose. The principal quantities involved in the construction of the head-works were 10,000 cubic yards of excavation, 330 cubic yards of embankment in dike, 330 cubic yards of concrete, 2,100 linear feet of round logs, 18,000 feet board-measure of lumber, and 400 cubic yards of paving.

Tunnels.—The original plans for the main canal provided for eleven tunnels, but as construction proceeded this number was reduced to five, having an aggregate length of 10,963 feet, the length of the individual tunnels being as follows:

Steeple Tunnel	103 ft. long
Trail Creek Tunnel	3,120 " "
Columnar Tunnel	1,200 " "
Tieton Tunnel	2,730 " "
North Fork Tunnel	3,810 " "

Steeple Tunnel consists of two short tunnels, 55 and 48 feet long, respectively, separated by 62 feet of open canal. They are located near the upper end of the main canal in a steep, rocky bluff, from which the tunnels were named. This tunnel is lined with the regular shapes used for lining the open canal, which required a heading 9 feet 6 inches in diameter, involving about 2.6 cubic yards of excavation per linear foot. The drilling was done entirely by hand, and about 24 feet of the tunnel were lined with timber. The rock was a dense quality of basalt somewhat weathered near the surface.

The Trail Creek Tunnel is located about 5 miles below the diversion works through an abrupt rock cliff which extends vertically to the river. The tunnel bore approximates a circle about 8 feet 3 inches in diameter. The lining has an approximately trapezoidal shape with about 4 feet bottom width, $\frac{1}{4}$ to 1 side slope, and a depth of 6 $\frac{1}{2}$ feet. The material excavated amounted to 2.3 cubic yards per linear foot of tunnel. The material was a

very hard basalt and required no timbering. The drilling was done with Adams electric drills, which were later superseded by Temple-Ingersoll electric air drills. This tunnel was a source of

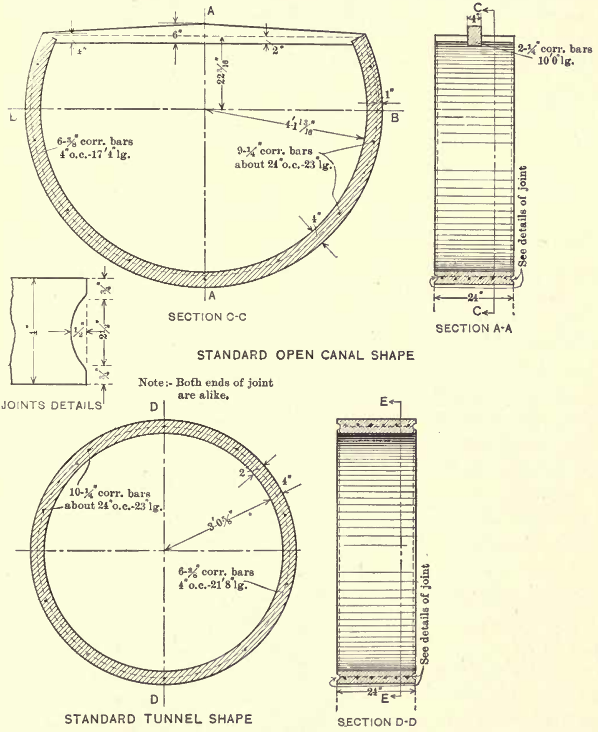


Fig. 115.—Tunnel and Canal Sections, Tieton Main Canal.

considerable trouble on account of the very hard rock and the requirement for experienced drill runners to operate the electric air drills, which quality of labor was not always readily obtained. Columnar tunnel is located about 3 miles down-stream from Trail Creek. It is circular in cross-section, with a bore 7 feet

3 inches in diameter. The material is a volcanic débris which was very easily driven. The quantity of material excavated was 2 cubic yards per linear foot of tunnel. Air drills were used with some hand drilling during breakdowns of the power supply. This was the easiest of all the tunnels to drive. The material drilled easily and required little powder to break and worked well to neat lines. About 1,200 feet of this tunnel required permanent timbering. The tunnel has a circular concrete lining 4 inches thick, built in 2-foot sections, which were manufactured in the central yard in the canyon below and hoisted up into the tunnel and grouted into place.

The Tieton and North Fork tunnels are located at the lower end of the main canal and are separated by a short stretch of open canal. The North Fork Tunnel pierces the divide separating the Tieton Basin from that of Cowiche Creek. The cross-section of these tunnels is circular, the diameter of the bore being 7 feet 3 inches, and the lining is similar to that used in the Columnar Tunnel. The material in the Tieton Tunnel is a hard clay with occasional soft spots. The quantity of material excavated amounted to 2.1 cubic yards per linear foot of tunnel. Air drills and electric air drills were used. The material was very variable in character, ranging from the loosest dirt to the hardest basalt, the hard rock predominating.

The material in the North Fork Tunnel is a basaltic formation very loose in places. The quantity excavated amounted to 2.4 cubic yards per linear foot of tunnel. Air drills were used. Noteworthy features of the construction of this tunnel were the presence of large quantities of seepage water, which required practically continuous pumping during construction and the looseness of the material, which required the timbering of 2,660 linear feet of the tunnel, or 70 per cent of the total length. From the lower portal of this tunnel the water from the main canal emerges into the valley in which the irrigation lands are located.

A noteworthy feature of the construction of the tunnels is the poor results obtained with the use of electric drills. These drills were operated by three-phase, sixty-cycle 220 volts alternating current. As the work progressed continual trouble was caused by the breakage of parts of the drills, the springs operating the rebound being especially susceptible to injury. Much delay was encountered in obtaining duplicate parts. In addi-

tion there was difficulty in obtaining drill runners skilled in the use of electric drills. Ordinary drillmen would generally refuse to use the apparatus, or if persuaded to make a trial, would obviously use it in an unsympathetic and ineffective way. Careful study, however, of the effectiveness of the electric drills, even when skilfully handled, showed that in very hard rock they were uneconomical, their penetrating power being low. Eventually, Temple-Ingersoll drills were substituted and the work was completed with them. These drills are practically air drills driven by an electrically operated air pump on a small truck. This apparatus was found to be much more effective than the electric drills for which they had been substituted, the blows being more forcible and the penetrations correspondingly more satisfactory. This apparatus, also, was found to be far less subject to injury than the electric drills.

Canal Lining.—The main canal in its length of about 12 miles, from the diversion point in the river to the lower extremity of the tunnel through the Naches Ridge, encountered practically every variety of material in its course, but at no point, excepting in the extreme upper 1,000 feet, was the formation such as to permit of the use of the ordinary type of unlined earth canal. Early surveys disclosed the fact that the greater part of the main canal would lie on side hill slopes averaging close to 60 per cent. The side hill material for the most part consisted of soils and gravelly clays, frequently intermingled with slide rock material and occasionally consisting wholly of loose rock. The earthy material in the side hill was found to be generally unstable during the spring, when frost was coming from the ground, and this instability was later found to be particularly noticeable in some of the slide rock material when lubricated by moisture and clay, which frequently occurred.

At first it was hoped that an ordinary unlined canal section in open cut might be used for some of the work, but this idea had to be abandoned, and later it became doubtful whether even ordinary concrete lining would hold the canal intact on the steep side hill slope after the tendency to cave and slide had become evident. The side hill material was found to lie mostly on the natural angle of repose. This became increasingly evident when it was observed that heavy sloughing and sliding of a highly significant character had occurred on the natural slopes when the

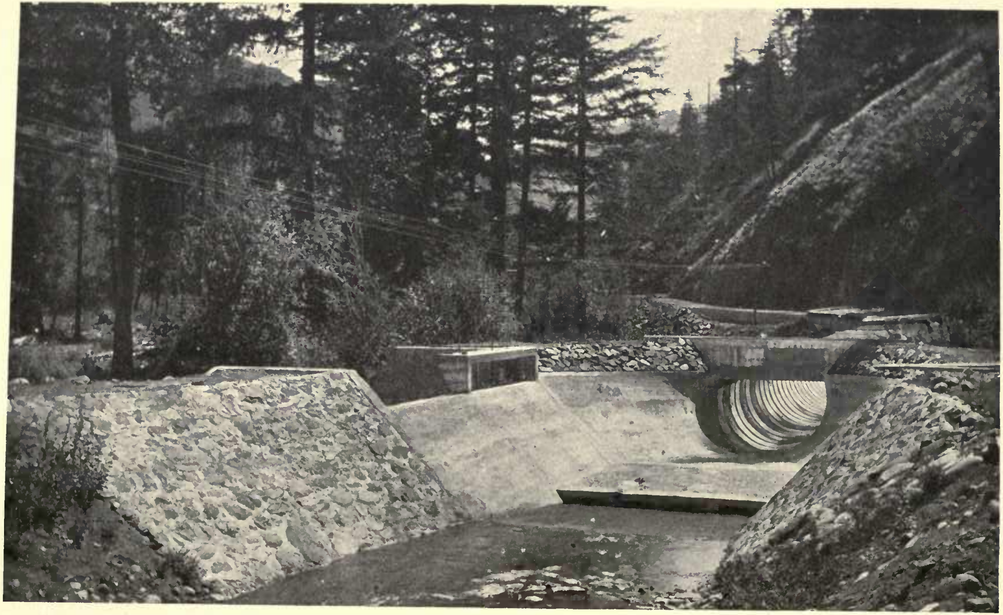


FIG. 116.—Sand Box and Transition to Lined Section, Tieton Main Canal, Yakima Project.

melting snow and rain had thoroughly saturated the upper side hill material, which was frequently fractured and jointed in every direction, with slippery clay seams, and disintegrating rapidly on exposure to the weather.

The conclusions reached in consequence of the aforementioned observations were: First, that the type of canal should involve as little disturbance of the natural side hill slopes as possible; second, that the canal should be self-sustained structure capable of resisting considerable external earth pressure on its upper side, and of sufficiently rigid cross-section to retain its integrity against internal hydrostatic pressure without depending on any support from the outside embankment. These requirements obviously eliminated the ordinary concrete-lined canal and pointed to flume construction as the probable solution. The objection to ordinary flume construction in this case was the absence of resistance to lateral earth pressure. A further and very important objection to either of these methods of construction was that the lining would have to be built in place. Gravel and sand in workable quantities could be found only along the bottom of the canyon. Water for sprinkling and mixing would have to be taken from the river, hundreds of feet below the canal location, except at its upper end; and, moreover, the transportation of building material and the conduct of building operations on the canal line would have been attended with much inconvenience on account of the steepness of the canyon walls and the narrowness of the ledge on which work would have had to be done. On the other hand, there were several flat areas in the river bottom which could advantageously be used as yards for manufacturing and curing the concrete lining in sections to be subsequently hoisted on to the canal line to be grouted in place. This method of construction was adopted.

Fig. 115 shows the typical cross-sections of canal and tunnel lining as constructed. The sections or shapes in which the lining was manufactured are of uniform length of 2 feet both for open canal and tunnel work. Each shape consisted of a slab of reinforced concrete 4 inches in thickness, molded to the desired shape. The reinforcement consisted of $\frac{3}{8}$-inch corrugated rods placed 4 inches from center to center. Each open canal shape was stiffened by a 4×6-inch cross-bar, which had for reinforcement two $\frac{3}{8}$-inch corrugated rods. The tunnel

shapes were complete cylinders. The concrete in these shapes is generally composed of one part of cement to ten parts of unmixed aggregate, the latter being proportioned so as to give a mixture as dense as possible. The shapes were all cast on their sides in steel forms. The forms were made of thin sheet steel riveted to steel angles and stiffened with suitable bracing of light angle iron. The forms for the open canal were made in four pieces, two inside and two outside. All tunnel forms were made in six pieces of similar construction, and were light, being handled easily by two men. The method of construction may be briefly described as follows:

At points along the bottom of the canyon level spaces each of a few acres in extent were selected and used as yards for manufacturing the shapes. These spaces were necessarily small in area, on account of the confined nature of the canyon, and occupied practically all the available space. At some of these points concrete material was at hand, but at others it had to be hauled from a distance. All open canal and tunnel lining shapes were cast at these yards. All mixing was done in cubical batch mixers, each batch exactly filling the mold. The open canal shapes contained about 0.47 cubic yard, and the tunnel shapes about 0.5 cubic yard.

In placing the mold the inside forms were first set up over a portable templet and bolted firmly together so that all shapes would have exactly the same inside dimensions. The inside forms when bolted together were then laid in their correct position on the ground, supported by four wood blocks. The outside forms were then placed in position spaced 4 inches outside of the inner form and held by wooden blocks and iron clamps. The next step was to prepare a firm and correctly molded base on which to tamp the concrete in the molds. This was obtained with a preparation of sand and plaster of Paris worked to the consistency of mortar and tamped to a thickness of about 1 inch in the bottom of the mold. The top of this plaster was readily brought to a smooth, even surface by a metal molding iron. The plaster of Paris hardened quickly into a tough mass which fully closed the bottom of the molds and gave an even bed on which to place the concrete. It also prevented the leakage of the finer portions of the concrete material. The concrete shapes, after being cast, were left undisturbed

Fig. 117.—Tieton Main Canal, Lined Section.

for intervals of from 24 to 36 hours before the forms were removed.

The shapes were permitted to lie in the yard for a period of not less than thirty days, after which they were raised from their beds and hauled to a point where they were loaded on special cars for delivery to the canal. From each yard inclined hoists, driven by electric motors, or cableways similarly operated, were used to deliver the loaded shapes to the canal line. The loaded cars when delivered on the canal line were made up into trains of four or five cars and hauled by horses along the temporary track laid in the canal-bed to the point where laying operations were in progress. Each shape weighed about 1,800 pounds, and in setting them in place it was somewhat difficult to adjust them accurately and speedily. When adjusted in position and carefully blocked, the shape was at once back-filled, the space between the bottom of the concrete shape and the canal-bed being from 4 to 6 inches. Much attention was given to the thorough tamping of the backfilling directly under the shape so that there should be no danger of subsequent settlement. The backfilling for a width of about 6 feet under the shape, therefore, was watched very carefully, and only selected material was used for this purpose.

On sharp curves, shapes molded a little narrower on one side than on the other were inserted, but on curves of large radius no specially molded shapes were used, the curvature being taken up entirely in the joints.

The joints were made of concrete with fine aggregate, the stone passing a ½-inch mesh. The joint was well filled, but before the concrete had set, the surface of joint in the interior of the canal was scraped off and a finish coat of mortar was trowelled on so that the finished surface of the joint was exactly flush with the surfaces of the shapes. The width of the joint permitted any small irregularity due to the placing of the shapes or in the dimensions of the shapes themselves to be taken up without any abrupt jog in the interior of the canal. The normal width of joints was 1½ inches.

The short Steeple Tunnel was lined with the regular canal-lining shapes. The other tunnels, with the exception of Trail Creek Tunnel, which was lined with a trapezoidal concrete lining built in place, were lined with reinforced concrete shapes built

in rings 2 feet in length. The aggregate length of the three tunnels so lined is 8,000 feet. The tunnel lining was cast in the yard in the same manner as the open canal lining, and the shapes were finally delivered in the tunnel on small cars. These cars were especially designed for lightness and compactness so that the empties could be readily lifted from the track and stacked temporarily in the tunnel, pending their return to the yards, without interference with delivery of the loaded cars.

Trail Creek Tunnel, which was not lined with the circular shapes, was driven through very hard and firm basalt, and as there seemed to be no necessity for a permanent arch for the roof, it was decided to omit it, in general, and build concrete lining in place by the usual methods. It was found, however, that the actual cost of lining and backfilling, which, in this case, included only the side walls and invert, exceeded the cost of the complete circular lining by the shape method as previously described. This was due principally to the excessive quantities of concrete required to fill holes and cavities in the sides caused by irregularities in blasting the tunnel. The experience derived from lining the tunnels for the Tieton Canal, with shapes cast in a yard, has demonstrated that this method of tunnel lining can be used advantageously for tunnels of moderate dimensions.

The excavation and preparation of the bed for the concrete shapes were attended with considerable difficulty because of the location of the canal, the steep slopes, and the numerous side gullies and gorges which broke the continuity of the side hills and required special treatment. The line was located so as to reduce the excavation to a minimum and also so that there should be the minimum disturbance of the natural slopes of the hill-sides. The natural slopes, however, were frequently so steep that 1½ to 1 slope on the upper side of the canal excavation would only intersect at a considerable distance above the canal line, so that, even with the shallow cut required for this type of construction, a large quantity of material had to be removed. Practically all excavation was by hand, the steepness of the hillside not permitting the use of animals or mechanical methods. Wherever the canal location was in earth a 4-inch drain tile was laid along the bottom of the trench on the side toward the hill, outlets for the drain being built at intervals of from 300 to 500 feet. This drain was for the purpose of taking care of

natural ground water or seepage water from the canal and preventing its accumulation and its tendency to soften the bed of the concrete lining.

The full canal at its capacity is designed to flow 5 feet 3 inches in depth, leaving a clearance of 9 inches under the cross-bars. It was estimated that the canal lining would have a coefficient of roughness of .012 in Kutter's formula and the resulting velocities would be 9 feet per second with a discharge of 300 second-feet. The finished inside of the tunnels, excepting the Trail Creek Tunnel, is circular in shape with a diameter of 6 feet 1¼ inches. The depth of flowing water in the tunnel at canal capacity was estimated at 5 feet 3 inches, leaving a maximum clearance of about 10 inches. The estimated velocity in the tunnels was 12.65 feet per second.

Notwithstanding the tortuous nature of the alignment of a large portion of the canal, observations subsequently made showed that the canal will, undoubtedly, carry its maximum capacity. The average of a number of readings showed that with 274 second-feet of water flowing the mean depth in the lined canal was 4 feet 7 inches, or 8 inches less than the estimated depth at full capacity. Further observations showed that the value of "n" in Kutter's formula varies from about .012 at the beginning of the irrigation season to about .013 at the end of the season. This is due to the formation of a slimy growth on the surface of the lining in contact with the water. After the irrigation season, when the canal is empty, this substance dries up and disappears, and the next season is begun with clear surface.

One of the first steps after the preliminary surveys was to build a wagon-road the entire length of the canal along the bottom of the canyon. A water-power-plant was constructed near the lower end of the canal to furnish power for driving the tunnels, advantage being taken of a steep fall in the river to build a power canal. The turbine installation at its lower extremity developed about 250 horse-power under a head of about 30 feet, the turbine being belt-connected with a two-stage air compressor and a generator for lighting and power purposes. Another hydro-electric installation was made near the upper end of the canal, making about 600 horse-power at the two power plants.

Wasteway.—A noteworthy feature of this canal is the wasteway system. During the construction of the canal the fact was

disclosed that frequently large boulders came tumbling down the hillside of such size as to be capable of completely demolishing a section of the canal. The danger of allowing a long stretch of the main canal on the precipitous mountainside to be unprotected by wasteways was apparent. Five wasteways, each capable of discharging the entire flow of the canal, were constructed at strategic points. The object was to provide immediate relief for the canal in case of a break, as it was recognized that such break, unless attended to almost instantly, would result in serious damage. As accidents might happen either by day or by night, it was necessary that the operation of these wasteways be automatic, and they were therefore planned to operate by means of floats in the canal which would respond to variations in the level of the water surface, and thus close an electric circuit operating the valves.

The wasteways are of two types; one of these consists of a cylindrical gate 6 feet in diameter and 2 feet high placed in a pocket adjacent to and about 10 feet below the bottom of the canal. The operation of the valve is caused by means of an electro-magnet operating a trip, which, when released, allows a lever with a counterweight suspended in practically a vertical position to drop, thereby hitting a horizontal lever attached to a cam, with the result that a knuckle joint is pushed out of its fixed position and made to collapse, due to the dead weight of the gate itself. This gate, dropping below its cap, allows the water to pour in on all sides and connection is made under the valve to a flume for discharging the water of the canal back into the river. This type of wasteway was to a considerable extent experimental, and it was found that it did not work with entire satisfaction, due principally to interference with the operation of the valve of pebbles and gravel that were washed along the bottom of the canal and lodged in the basin in which the valve is located. This type of valve was used for two of the wasteways.

The other three wasteways have a 4 × 5 cast-iron sluice-gate which is operated by a 10-inch vertical wicket-gate turbine, the turbine being located just outside the wasteway pit with its intake at such an elevation that the sluice-gate is entirely opened when the receding water falls to the center of the intake opening. The turbine shaft is connected to the main gate shaft through a system of gears. To the turbine gate shaft is attached a drum

around which a small cable is wound, having on its end a suspended weight. When the turbine gate is closed the weight is suspended and holds a projecting pin from the handwheel against the magnet release, which is electrically connected with floats placed at intervals along the canal. An abnormal change of water surface in the canal makes a connection at the float that causes the magnet to release; the dropping of the weight opens the turbine gates, which starts the turbine, and the turbine opens the wasteway gates. When the falling water drops below the turbine intake the machinery ceases. To close the gate the operation must first be started by hand until the water rises in the pit sufficiently to enter the turbine intake, after which the clutch may be thrown in and the gate closed by power. The system is laid out in such a manner that the maximum time required to empty the stretch of canal between any two wasteways is from 15 to 20 minutes.

Distribution System.— On emerging from the last tunnel through the Naches Ridge the water is delivered into the north fork of Cowiche Creek, from which it is diverted at five points by low earth diversion dams into eight main laterals. From these laterals numerous smaller ones extend to all parts of the project, carrying water to each 40-acre subdivision.

Cowiche Creek traverses centrally the northern half of the project lands. The country has a fall of about 100 feet to the mile. It was found advantageous to use the creek as a main supply artery and divert the laterals at stratgeic points as required. The earthen dams that divert the water from the creek into the main laterals are simple, inexpensive structures paved on the up-stream side and across the spillway channels, which are designed to safely discharge the annual flood that results in the creek by melting snows in the hills near the headwaters of the same.

In addition to the use of the main channel of Cowiche Creek as a main supply canal, the practice of using natural watercourses for carrying irrigation water was followed throughout the project wherever possible. They were used as main distributaries and small diversion dams were constructed across the channels where it was desired to divert the water into sublaterals. These diversions were usually made by small concrete headings, the flow of water being controlled by either circular cast-iron gates or

FIG. 118.—Steel Flume, Tieton Distribution System, Yakima Project.

by flash-boards. The ravines used in this manner usually had rock or cement gravel bottoms and required very little improvement. The use of these natural drainage channels resulted in a large saving of cost in original construction and also in the cost of maintenance.

The topography of the entire irrigable area is very rough, which necessitated the use of a large number of siphons for reaching isolated areas and conducting the water across ravines. Where the elevation of a crossing was less than 12 feet, flumes were generally used. For heads greater than 12 and less than 20 feet, plain concrete pipe of small diameter was used.

For the higher heads reinforced concrete pipe of small diameter was used with considerable success and economy. About 20,000 linear feet of such pipe were used, varying in diameter from 8 inches to 14 inches and being subjected to heads of from 26 feet to 115. The reinforcement consisted of a wire fabric as a base on which was wound in a helical coil the main reinforcement, which was No. 12 gage wire. The spacing was adjusted in accordance with the head to which the pipe was to be subjected. The cost of manufacturing and laying these pipes is given in the following tabulation:

MANUFACTURE OF REINFORCED-CONCRETE PIPE

Size	8″ Diam. 1⅛″ Shell	8″ Diam. 2″ Shell	10″ Diam. 2″ Shell	12″ Diam. 2″ Shell	14″ Diam. 2″ Shell
Total Linear Feet	3,207	8,342	5,781	5,325	1,867
Cost per Foot	$0.063	$0.057	$0.055	$0.064	$0.073
Mixing and placing	.014	.014	.010	.013	.011
Finishing	.014	.014	.010	.013	.011
Sprinkling	.006	.006	.005	.005	.006
Cement	.051	.063	.070	.082	.096
Sand and gravel	.033	.038	.045	.051	.055
Reinforcement	.050	.071	.066	.087	.094
Tar paper and fasteners	.042	.034	.034	.034	.042
Plant construction	.032	.031	.034	.049	.075
Plant maintenance	.028	.034	.042	.048	.055
Equipment depreciation	.006	.007	.008	.012	.018
Total	$0.325	$0.355	$0.369	$0.445	$0.525

Material:		
Cement	$2.50	per bbl. f.o.b. plant
Sand	2.00	" cu. yd. " "
Aggregate	2.00	" " " "
A. S. & W. Style 7 fabric	0.0395	" lbs. " "
No. 12 annealed wire	0.03	" " " "
Tar paper	0.002	" sq. ft. " "
Labor:		
Foreman	$125.00	per month
Tampers	2.80 to $3.00	per day
Fillers	2.40 " 2.60	" "
Finishers	2.40	" "
Sprinkler	2.60	" "
Mixer tender	3.00	" "
Laborers	2.00	" "

Hauling and Laying Reinforced-Concrete Pipe

Items	Cost per Linear Foot			
	8″	10″	12″	14″
Excavation trench	$0.130	$0.132	$0.162	$0.180
Laying and jointing	.093	.118	.146	.168
Backfilling trench	.020	.024	.020	.045
Haulage on pipe	.043	.051	.059	.068
Cement for jointing	.025	.039	.041	.048
Sand and water for jointing	.025	.041	.044	.049
Total	$0.336	$0.405	$0.472	$0.558

SUNNYSIDE UNIT

The Sunnyside Unit comprises a body of land containing about 103,000 acres and extending from a point about 8 miles southeast of North Yakima to a point about 6 miles east of the town of Prosser. The project has an elongated shape with a total length of about 50 miles and a maximum width of about 8 miles. About 10,000 acres are on the south side of the Yakima River east of the Yakima Indian Reservation. The remaining lands are on the north side.

A large part of the lands included within the Sunnyside Project was originally owned by the Northern Pacific Railroad Company, and this company was naturally the first to make investigations of the feasibility of irrigating the same. Their engineers made several adverse reports, but in 1889 a company was formed

for constructing a canal for supplying these lands. This company together with its several successors constructed the main canal to a capacity of about 650 second-feet at the intake, together with some of the main laterals, and in 1906, when the Reclamation Service acquired the system, there were about 30,000 acres under irrigation.

Investigations of this project by engineers of the Reclamation Service left no doubt as to the feasibility of enlarging the system and extending the same to cover a much larger acreage. Furthermore, to allow the Reclamation Service to enter upon the development of other projects in the Yakima Valley, it was necessary that the United States obtain control of the water rights owned by the Sunnyside Canal. This, together with the almost unanimous opinion of land-owners that the Reclamation Service should take over the system, led to its acquisition by the United States.

The system was purchased by the United States in 1906, and shortly after said purchase construction work looking toward the enlargement and improvement of the system was begun. At the present time about 80,000 of the 103,000 acres included in the project are supplied with water, and the main items of work accomplished are listed in the following tabulation:

31 miles of open canal over 800 second-feet capacity.
19 miles of open canal from 301 to 800 second-feet capacity.
33 miles of canal from 50 to 300 second-feet capacity.
442 miles of laterals less than 15 second-feet capacity.
6,300 canal structures of various kinds and materials.
121,000 feet of concrete, metal, clay, and wood pipe.
About 204,000 linear feet of concrete, metal, and wooden flumes.

The total quantity of excavation involved in the construction of the canals is about 2,800,000 cubic yards.

ENLARGEMENT AND IMPROVEMENT OF THE SYSTEM

The work done by the Reclamation Service on the Sunnyside Project included the following main items:

Construction of new diversion works, enlargement of the main canal and main laterals, extension of the distribution laterals, the construction of a large number of concrete drops, culverts, and turnouts on the main canal, construction of two main wasteways and the construction of two pressure pipes to carry

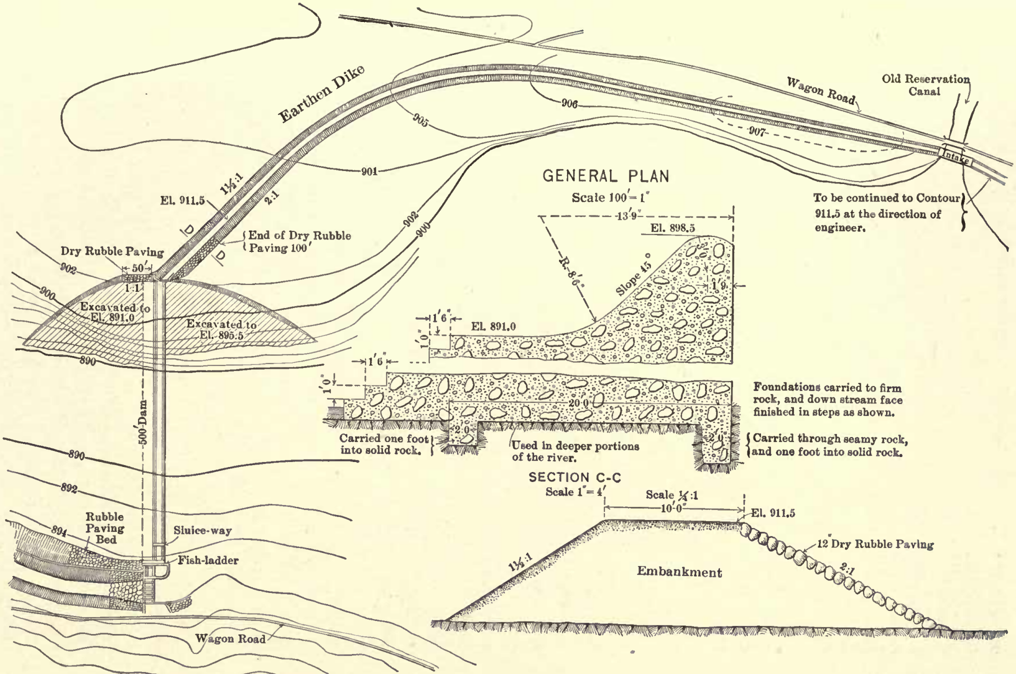


FIG. 119.—Plan and Sections, Sunnyside Diversion Dam.

water from the main canal to supply lands on the south side of the river.

Diversion Works.—The diversion works for the Sunnyside Canal are located on the Yakima River about 8 miles southeast of North Yakima. At this point in the river an outcrop of bed-rock is close to the surface for nearly the full width of the stream and forms an excellent foundation for the diversion dam and head-gates. The dam constructed by private enterprise consisted of a series of steel brackets fastened to a concrete foundation and spaced 6 feet apart across the entire length of the dam, which was 360 feet long. When upright, these brackets extended 6 feet above the concrete floor, and a dam of this effective height could be made by using 2 × 8 × 12-inch flash-boards on the inclined up-stream face of the brackets. In high water, when no dam was needed to divert water into the canal, the flash-boards were removed and the brackets folded over sidewise so as to lie flat on the concrete foundation. In low-water stages the brackets were raised by means of chains and the flash-boards inserted as needed to obtain the required diversion into the canal. At the north end of the dam there was a masonry gate-house which served as the dam abutment, and between this gate-house and the shore a timber bulkhead with five 6 × 6-foot openings, which were closed by wooden gates. The headworks were of temporary construction and rather unserviceable. The dam was little better, and, moreover, the raising and lowering of the brackets of this dam were accomplished with considerable difficulty and danger owing to the sudden floods which frequently occur in the Yakima River, so that when plans were made by the Government for a new headworks to fulfill the requirements of the enlarged canal, it was considered necessary to abandon this movable dam and to construct one with a fixed crest. As the lands up-stream from this dam are quite low and flat, it was necessary to construct a dike for some distance up-stream to protect these lands during high water.

The new dam is of concrete of the ogee type, 8½ feet high and 20 feet wide, including the apron. The total length of this dam between abutments is 500 feet. The new headworks structure is also of concrete of the ordinary type, containing six 6 × 6-foot openings closed with cast-iron gates operated by hand. The opening and closing of these gates by hand are a rather slow process,

and in order to stop the flow of the water into the canal quickly in case of an emergency, such as a break in the canal banks, Tainter gates were installed directly back of the cast-iron sluice-gates. These gates are pivoted on a 2½-inch steel shaft and are held open by steel chains run to the floor of the structure where they are held by keys. When it is desired to shut off water in the canal quickly these keys are withdrawn and the gates dropped into place, thus closing off the water. The usual flash-board grooves above and below the main gates are also provided to allow the cutting out of any one of the gates for repairs without interfering with operation of the remaining gates. The earth dike on the south side of the river extends about 1 mile up-stream. It has a top width of 10 feet and the level of the top is 13 feet higher than the crest of the dam.

Excavation for Enlargement of Main Canal.—This work presented a serious problem. It was obviously very undesirable to excavate any material from the embankment side of the canal. It was desirable that most of the excavated material be deposited on the lower side, especially where the lower side was in embankment. Furthermore, over a large portion of the canal, it was very uneconomical to deposit the material on the upper side on account of the deep cut. Moreover, in order to do the work continuously and economically, it was necessary to excavate while water was running in the canal, as the supply of irrigation water could not be interrupted during the irrigation season. These requirements obtained especially in the first 30 miles of the canal. Below the thirtieth mile the cuts were in general not so deep and the fills not so high, and the canal was, of course, considerably smaller.

The necessity for excavating with water in the canal made imperative the use of machinery for this excavation; the main portion of the work was consequently done in this manner. Some of the very deep cuts and some places where the material was too hard for the machines to handle were excavated by teams. On the upper 22 miles of the canal a continuous bucket elevator dredge with belt conveyors was used. This type was selected principally for its adaptability to mounting on a floating hull and the long reach of its conveyors. Below the twenty-second mile a drag-line excavator was used. This machine was operated from the upper bank and its reach was sufficient to reach the

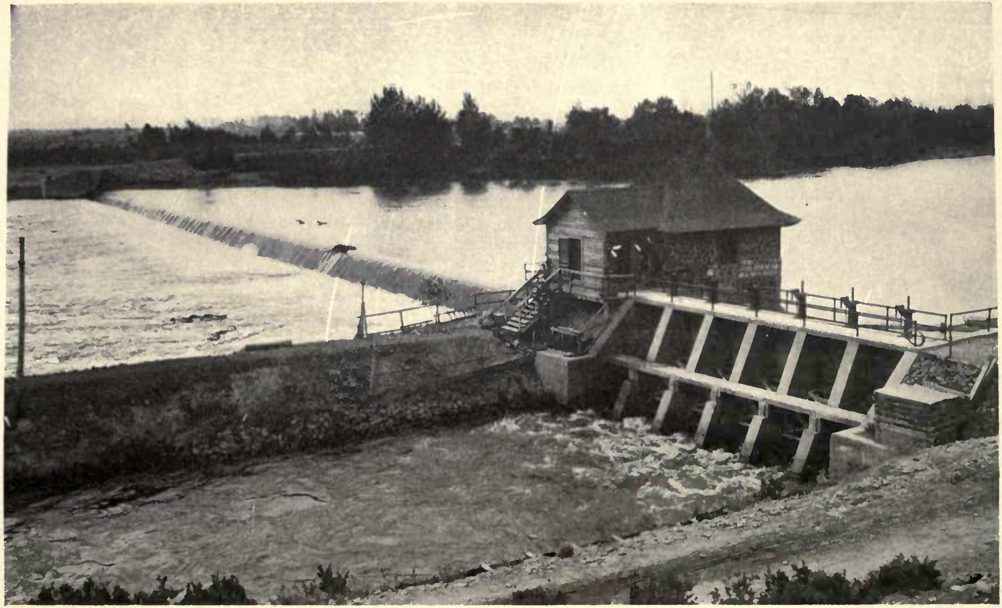


FIG. 120.—Dam and Head-gate, Sunnyside Canal.

opposite bank and excavate the full section while depositing the material on the upper side. The concrete drop structures through which the dredge had to pass had a clearance of only 32 feet between abutments, and it was therefore necessary to keep the width of the hull within about 30 feet out to out. This narrow width of hull with the great massive machinery to support made it rather unstable and hard to handle. The dredge was a 3½-cubic-foot steam-driven continuous bucket elevator type with an 82 × 30 × 6½-foot hull drawing 5 feet of water. Steam was furnished by two 80-horse-power locomotive type boilers. The main drive and ladder hoist were driven by a 70-horse-power double horizontal engine; winch machinery for spuds and for swinging the dredge was driven by a two-cylinder 20-horse-power double horizontal engine. Conveyors were driven by the two 18-horse-power single cylinder horizontal engine. A hydraulic giant was mounted on the bow to remove banks above the water-level and beyond the reach of the buckets. The conveyors were 72 feet long and had seven-ply 32-inch rubber conveyor belting. The drag-line excavator was a Lidgerwood-Crawford 1½-cubic-yard bucket machine with a 60-foot boom. It was steam-driven with a 48 × 114-inch vertical boiler and a 9 × 10-inch double cylinder engine. A 6 × 6-inch double cylinder engine was used to turn the machine.

The finished canal section excavated by the dredge has a bottom width of 44 feet, a water depth of 8 feet, and a normal depth to the top of banks of 12 feet. The finished section of canal excavated by the drag-line machine has a bottom width of 26 feet, a water depth of 7.3 feet, and a normal depth to top of banks of 11.3 feet. In each case the total cross-sectional area of the finished canal is about double that of the original cross-section.

Drops, Culverts, and Turnouts.—The enlargement and improvement of the main canal involved, besides the excavation, the construction of numerous concrete drops, culverts and turnouts to provide for the larger quantities of water to be carried and to correct defects in the original design of the canal.

The velocities in the canal as originally constructed were in many places too high even for the then designed capacity; a number of wooden checks had been constructed in the canal to correct this and to hold the water up to the higher turnouts,

but these all required replacing. The enlarged canal also required less grade for given velocities, which made necessary the taking up of the excess grade in vertical drops at various points. Twenty-five such structures were built, in which the drop in the water surface varied from 0.5 to 2.25 feet. Twenty-two of these structures are of similar construction, the other three being adjuncts of turnout structures for main laterals and wasteways.

The design of these structures is simple, consisting of gravity abutments 32 feet between faces, on either side of the canal, with low walls and a check basin 2 feet deep between. The check basin is divided into five bays by concrete piers, on the top of which are anchored removable structural-steel brackets with stop-plank grooves. The water at most of these drops has a depth at full capacity of 8 feet. The drops were built before the canal was enlarged and the steel brackets were made removable to allow the passage of the dredge used for excavating.

Numerous culverts of various sizes were built under the canal to pass drainage water. The canal had been previously constructed with only a few small pipes at various points, but experience had with large flows of drainage water from the hills above and serious breaks in the lower banks resulting therefrom made imperative the construction of culverts. The smallest of the culverts constructed is designed to discharge 100 cubic feet per second and the largest 800 cubic feet per second. Since their construction no further trouble has been had from drainage water. The smallest culvert has a single rectangular barrel of reinforced concrete, $2\frac{1}{2} \times 3$ feet in cross-section, with the usual wing and cut-off walls at the ends. The largest culvert consists of three barrels, each $3\frac{1}{2} \times 6$ feet in cross-section.

The turnouts for laterals in the old canal were all of wooden construction and required renewal. In many cases also they had to be larger to supply increased areas to be supplied. The capacity of these structures varies from about 1 cubic foot per second for the smallest to about 180 cubic feet per second for the largest. The smaller structures have concrete pipes through the bank with simple cast-iron or structural-steel gates. All turnouts are supplied with Cippoletti weirs for measuring the water. The larger structures generally have rectangular barrels with common cast-iron slide-gates with hand-operating mechanism. The 180-second-foot turnout is so located that water-power can be

obtained for operating a small turbine, the power of which is used for operating the gates.

Wasteways.—There is not a single well-defined natural drainage channel crossing the path of the main canal in its whole length of about 60 miles. The problem of providing necessary wasteways for purposes of regulation and for emptying the canal quickly in cases of emergency was consequently a very difficult one. At Zillah, about 17 miles from the diversion works, the canal approaches to within 2,200 feet of the Yakima River, thus making a favorable site for a wasteway, although an artificial channel had to be constructed from the canal to the river. The other diverts from the canal at a point about 37 miles from the diversion. This wasteway traverses the widest part of the project, and in that respect the location is very unfavorable. However, the territory through which the wasteway channel passes was in great need of a main drain, and this wasteway was therefore constructed to serve the purposes of a wasteway for relieving the main canal and also as the main drain for carrying the seepage water from the tributary lands to the river. This channel is called the Sulphur Creek wasteway, and is artificial throughout.

The Zillah wasteway has a drop of about 120 feet from the water surface in the canal to the water surface in the river, the horizontal distance being 3,200 feet. The structure consists of the headworks, about 820 feet of trapezoidal channel with a 6-inch concrete lining, a 5 × 6-foot concrete cut and cover section 500 feet long, a 6 × 7-foot wooden flume 700 feet long, at the end of which the water discharges into the river. The headworks structure consists of a large drop chamber in the main canal, approximately 20 feet long by 50 feet wide, with an average depth of 8 feet, the depth of the chamber being variable on account of the slope toward the wasteway gates. On the up-stream side of this chamber and perpendicular to the center line of the main canal is a weir wall 48 feet long, having its crest approximately 4 feet above the bottom of the canal and being divided into 8 bays by steel brackets located 6 feet apart and anchored to piers back of the weir wall. Each of these brackets has a set of stop-plank grooves on the up-stream face. The downstream wall is an unobstructed wall about 2 feet lower than the up-stream wall. The water is discharged into the wasteway through four 4 × 5 gate openings, the flow being regulated by

cast-iron gates operated by hydraulic power. All four gates are operated from a line shaft actuated by a 9-inch water turbine located in a 4 × 4-foot concrete penstock at one end of the bulkhead wall in which the gates are located. The wasteway channel is about 15 feet lower than the canal, which fall is made use of for operating the turbine.

The wasteway is designed to carry the full capacity of the canal, which, at this point, is about 1,000 cubic feet per second. The velocity through the gates when the full capacity is flowing is approximately 13 feet per second, and the slope of the discharge channel is such that this velocity is increased to about 35 feet per second at the intake of the covered concrete section, and before reaching the river the water acquires an average velocity of about 40 feet per second. These velocities are based on a value of "n" in Kutter's formula of .013 for concrete and .012 for the wooden channel. Observations made on the flow through this channel since the construction was completed indicate that these velocities may be considerably exceeded. This wasteway discharges more or less water during the greater part of each irrigation season, and after five years of use no particular wear on the concrete or wood portion of the structure has been noticed due to the high velocities.

The Sulphur Creek wasteway consists of the headworks, about 1 mile of segmental concrete-lined channel, and about 7 miles of earth canal with concrete drops to take up excess grade. The headworks are a reinforced concrete structure similar to that of the Zillah wasteway, the only essential difference being that the headworks of the Sulphur Creek wasteway leave the canal at an angle of approximately 135 degrees, while those of the Zillah wasteway leave the canal at right angles. The capacity of this structure is 500 cubic feet per second. The discharge into the wasteway is through three 4 × 4 gate openings regulated by cast-iron gates which are operated by a water turbine with mechanism similar to that of the Zillah wasteway. After passing the gates the water discharges through three 4 × 4 concrete tubes for a distance of 52 feet, where a transition occurs in the next 38 feet to a trapezoidal section having a 7-foot bottom width and 5-foot 6-inch depth, and 1 to 1 side slopes. The slope of the channel from this point on is such as to accelerate the velocity of the water, which is kept at a uniform depth of 4 feet, by gradually

Fig. 121.—Sulphur Creek Wasteway; Head-works and Drop, Sunnyside Canal, Yakima Valley, Washington.

contracting the bottom, the side slopes remaining the same. This gradual contraction continues for a distance of 310 feet, at which point a warped section 60 feet long is introduced, which changes the channel from a trapezoidal section to a semicircular section having a radius of 4 feet. The semicircular section runs from this point to the end, a distance of 4,900 feet. The velocity of discharge through the gate at the intake is 10 feet per second, and this gradually increases down to the circular section, in which the average velocity is 22 feet per second.

Upon entering the unlined channel it was necessary that this velocity be decreased to about 2.5 feet per second, and to accomplish this a rather unusual structure was constructed at the end of the lined channel. This structure is of concrete, rectangular in plan, having inside dimensions of 14 × 18 × 18 feet high, with walls and floors 18 inches thick. The 14-foot end walls are solid and the two side walls each have 12½ × 4-foot rectangular openings through which the water coming into the end of the box near the top discharges outward into the unlined channel. In passing through this structure the water is turned through practically three right angles, and it has been found that this structure accomplishes its purpose very satisfactorily, the water from the check basin flowing down the unlined canal in a very quiet condition.

For the next 7 miles the channel is in earth, it has no lining except at the bottom, which is a timber lining having 2 to 1 side slopes intersecting at the lowest point and running up to a width of 8 feet at the top, with 1-foot vertical walls on the sides and the necessary loading planks extending into the bank. The earth channel has 1½ to 1 side slopes, but it was found necessary to vary these at some points on account of the unstable condition of the material. When only drainage water is flowing in the channel the water does not rise above the wood lining, but when the channel is used as a wasteway for the full discharge of 500 cubic feet per second the water flows at a depth of about 8 feet, and the wooden lining is then entirely submerged. There are 17 concrete drop structures in this channel through which the water surface is dropped through various heights from 2½ to 5½ feet. The drop structures are of somewhat unusual design, the unusual parts being the upper weir wall, which was made in the form of a half hexagon. The reason for the adoption of

this type of wall for the upper weir was to get additional length without extending the entire structure, and further, that with water coming into the drop basin from three directions its dynamic force is dissipated more effectually. The abutments are reinforced-concrete slabs supported at the bottom by the floor of the drop basin and at the top by a pair of 12 × 20-inch beams running between the abutments with a floor over the top to serve as a foot-walk. The drop basin has a depth below the top of the down-stream weir walls equal to the height of the drop. When only drainage water is flowing it does not pass over the top of this weir wall, but orifices at the level of the bottom of the wood-lined channel are cut through the weir wall to pass this drainage water. The cross-section and the grade of the channel were adjusted in such a manner that the water flows with a cleansing velocity when only drainage water is flowing in the wooden lining and will have a velocity not exceeding 3 feet per second when the full discharge of the wasteway is flowing.

Inverted Siphons.—Two inverted siphons or pressure pipes were constructed across the Yakima River for the purpose of supplying water for lands on the south side of this stream. The Mabton pipe crosses the river at a point about 5 miles east of the town of Mabton and supplies water for about 9,000 acres of land. The Prosser pipe crosses the river at the town of Prosser and supplies water for about 2,500 acres. These pipes are very similar in construction, the distinguishing difference being the size. Each consists of short lengths of concrete pipe at the upper and lower ends with wood-stave pipe between. The purpose of this form of construction was to have the wood pipe at all points at such a distance below the hydraulic grade line that there would always be at least 20 feet head on the wood, in order to keep it continuously saturated.

The water for the Mabton pipe is supplied from the main canal through a feed canal about 8,000 feet long. A large portion of this channel is in a deep cut, and the material through which it passes is coarse gravel. Considerable difficulty was encountered when the water was first turned in for priming; at first a flow of about 30 second-feet entirely disappeared from the bottom and sides of the channel, but after about three weeks of puddling the seepage was reduced to an insignificant amount. Measuring weirs were maintained at either end of the canal and ac-

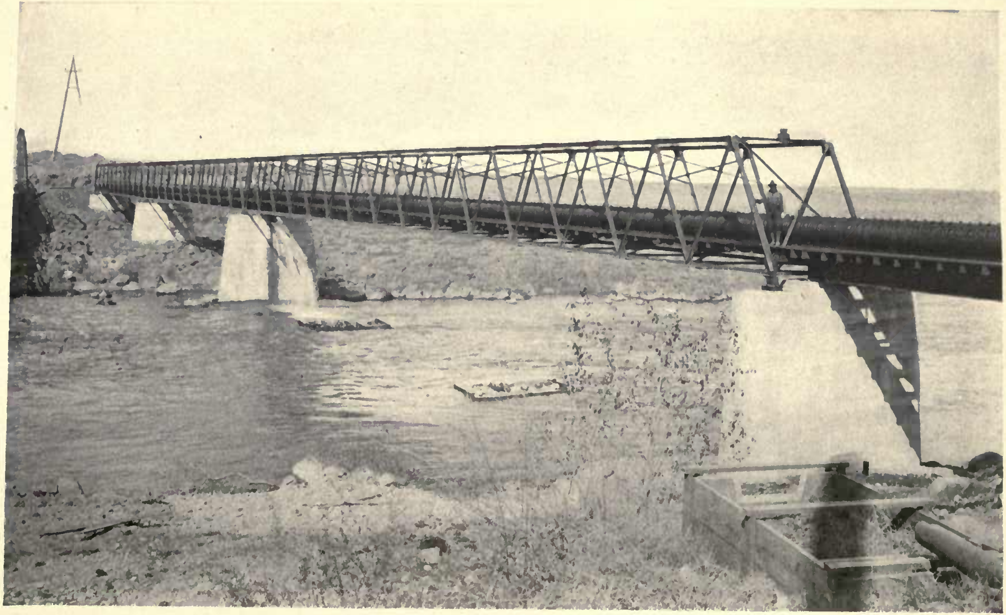


Fig. 122.—Steel Bridge and Wood-stave Pressure Pipe, near Prosser, Washington, Yakima Project.

curate measurements were kept of the seepage losses until the difference in the measurements was practically nothing.

The pressure pipe consists of 3,000 feet of 54-inch concrete pipe at the upper end, 100 linear feet of 54-inch concrete pipe at the lower end, 1,500 linear feet of 48-inch wood-stave pipe in the lowest part of the profile where it crosses the river, and 11,000 linear feet of 55-inch wood-stave pipe forming the principal portion of the siphon.

The concrete pipe has a shell thickness of 3½ inches and is reinforced with 5/16-inch diameter wire wound in a helical coil and spaced in accordance with the head. The greatest spacing is 4 inches and the smallest 1½ inches. The pipe was manufactured in a yard in sections 5 feet long with a 1½-inch tenon at either end for the reception of connecting collars; these collars were also made in sections in the yard and were grouted on the pipe in the trench. The pipe is laid with the top about 2 feet underground. After the entire pipe had been laid, the inside surface was finished off with two coats of neat cement wash, which formed a very smooth and water-tight interior.

There are two sections of 55-inch pipe, one on either side of the river. The crossing under the river and for a short distance up the slope on either side was made with 48-inch pipe, the total length of this pipe being 1,500 feet. The portion of the pipe under the river is under a head of about 170 feet, and it was found more economical with a given total loss of head to make the portion under the river of smaller pipe and make the remainder correspondingly larger than it would have been to use a uniform diameter throughout. The staves in both the 55-inch and 48-inch pipes were 2½ inches thick and 5½ inches wide through the center. All bands were ⅝ inch in diameter, and two shoes were used for each band. On the north side of the river the pipe passes through cultivated fields, and it was necessary to bury it with the top approximately 2 feet underground. On the south side of the river the pipe passes through a body of non-irrigable land and is laid largely on rockfill and partly through rock-cut. Where exposed the pipe after completion was painted with a red oxide and linseed oil paint.

The width of the river where the pipe crosses it is about 500 feet. The pipe was placed with its top about 3 feet below the bed; it is held in this position by a 3 × 12-inch yoke over the

top and bottom of the pipe placed at intervals of 10 feet and fastened at either end to round piling, which was used in the construction of the cofferdam for opening up the trench. The principal reason for building this pipe under the bed of the river rather than using a bridge crossing was the absence of suitable foundation for piers for such a bridge. This method also appeared to be cheaper in first cost and more permanent construction, as the wood in the pipe in this position would have a very long life and the life of the pipe would be determined by that of the metal parts.

Subsequent experience disclosed some unlooked-for difficulties: Two years after the pipe was finished several leaks developed in the pipe under the river-bed, which, upon examination, were found to have been caused by the cutting in two of several bands followed by the breaking off of the butt ends of the staves. The bands were evidently cut through by a sand-blast action from the high velocities of discharge of small leaks. The pressure of the water at this point is about 170 feet and the resulting velocity was evidently sufficient to create a very effective cutting action on the bands. The pipe was in operation at the time the leak occurred and the services of a diver were necessary to ascertain the cause of the leak and to make repairs. The repairs consisted of removing the broken bands and placing steel plates on the inside and outside of pipe and placing new bands around the outside. Since the occurrence of the above-mentioned breaks, the pipe is inspected periodically from the inside and incipient leaks are repaired before they approach a dangerous size.

On the south side of the river, where the pipe is exposed and painted, it is, in general, in excellent condition after six years of use. On the north side of the river, however, where it is buried underground in porous soil, rapid deterioration of the staves has taken place, and it has been found necessary to replace a considerable portion of this pipe. The trouble here is that, although the pipe is kept full of water throughout the year, the seepage of the water and evaporation of same away from the pipe through the porous soil are so rapid that the staves are not kept thoroughly saturated at all times, resulting in very rapid decay.

The Prosser pipe is supplied with water from the main canal through a feed canal about ½ mile in length, for the purposes

FIG. 123.—Young Irrigated Orchard, Yakima Project.

of which a natural drainage channel is used, with the exception of about 400 feet in length, which is an artificial earth channel. The pressure pipe consists of about 2,850 feet of concrete pipe at the upper end, 275 feet of concrete pipe at the lower end, and 7,500 feet of wood-stave pipe between. The concrete pipe has an inside diameter of 30½ inches and shell thickness of 2½ inches. The pipe was built in sections 6 feet long in a central yard. Each section weighed about 1,500 pounds. These sections were hauled to the line and were there connected by means of segmental collars grouted into place, these collars also having been built in the central yard. The maximum head on the pipe is about 50 feet. The reinforcement consisted of No. 4 wire wound into helical coils on a reel, and three different spacings were used, viz., 1¾, 2½, and 3½ inches.

The wood pipe has an inside diameter of 31 inches. The staves are 2 inches thick and the bands ½ inch in diameter with malleable iron shoes. This pipe is carried across the river on a steel bridge consisting of two 132-foot steel Warren girder spans, one 180-foot steel Warren girder span, and one 50-foot I-beam span. The bed of the river at this point is solid rock, with the exception of a short distance on the south side, which is very hard, cemented gravel. The nature of this foundation made it much cheaper to build a crossing with a bridge for the piers, for which there was excellent foundation, rather than to excavate a trench in the solid rock of the river-bed for imbedding the pipe. The approaches to a pipe built under the river-bed would also have been in very deep rock-cut, and consequently very expensive. The experience with the Mabton pipe previously described would seem to indicate that the overhead crossing by means of a bridge is in any case much the better practice unless such type of crossing is very much more expensive. The advantage of having a pipe of this kind built in the open and capable of being easily and frequently inspected is obvious.

The Yakima Project was planned and largely built under the general direction of D. C. Henny as Supervising Engineer. Bumping Lake and Kachess Dams were built by E. H. Baldwin, and Keechelus Dam by C. E. Crownover. The canal systems were built under the direction first of Joseph Jacobs and later of Chas. H. Swigart, as Project Engineers.

CHAPTER XXII

SHOSHONE PROJECT

DESCRIPTION

The Shoshone River rises in the interior of Wyoming, and runs northeasterly into the Big Horn. Its headwaters drain the eastern part of Yellowstone National Park, at altitudes between 7,000 and 10,000 feet.

About 60 miles from its head it emerges from the mountains into a small valley, where it is joined by its principal tributary, called the South Fork, and then cuts through an abrupt granite spur, beyond which the country opens out in the form of a terraced plain, through which a canyon conducts the river to its mouth at the Big Horn.

The granite gorge above mentioned, occurring just below an open valley, forms a site for a dam capable of impounding a large amount of water.

The Shoshone Project provides for the storage of water at the site mentioned, which is about 8 miles from the town of Cody, and its diversion at various points to irrigate the bench land on both sides of the river.

Early irrigation development from this river was accomplished by the diversion of the waters of the south fork of the Shoshone, from which the lands on Irma Flat and those around Cody were irrigated, and the waters of the main stream were diverted and applied in the vicinity of Lovell, Byrum, and Kane, Wyoming. These uses were sufficient to practically exhaust the natural flow of the river in the late summer of low-water years, and it was thus impossible to inaugurate any large extension of irrigation without storage. Investigations were therefore made with a view to the construction of a storage reservoir to impound the winter flow and the surplus discharge of May and June during the melting of the mountain snows.

SHOSHONE RESERVOIR

At the entrance of the gorge about 8 miles above Cody, a site was selected where a high masonry dam would form a reservoir covering a large flat above the gorge and backing water up both the north and south forks of the river. Surveys and borings were made, and a dam was designed on a radius of 150 feet, to reach a height of 240 feet above the river-bed, with a spillway 10 feet lower. The reservoir formed by this dam has the following dimensions:

AREA AND CAPACITY OF SHOSHONE RESERVOIR

Elevation, Feet above Sea	Area, Acres	Added Capacity, Acre-Feet	Capacity, Acre-Feet
5,140	2	....	....
5,160	21	194	295
5,180	121	902	1,598
5,200	316	2,498	5,168
5,220	666	5,646	15,161
5,240	1,181	10,336	33,256
5,260	1,785	16,214	62,666
5,280	2,444	22,762	104,898
5,300	3,363	31,161	162,623
5,320	4,317	40,686	239,224
5,340	5,377	51,112	336,150
5,360	6,604	63,110	456,000*
5,380	8,000	144,000	600,000
5,400	9,500	160,000	760,000

* Spillway.

Access to the Shoshone Canyon was made possible by a road started in the spring of 1904 as a rough trail over which to transport drilling machinery. This was afterward improved to the condition of a good wagon road, suitable for freighting. Three tunnels were built for the road between Cody and the dam site, and the site itself was passed by a tunnel above the left abutment. This road was continued westward up the north fork of the Shoshone River to serve as a road to Yellowstone Park and to replace the road formerly serving this purpose and submerged by the reservoir. The precipitous location necessitated several tunnels on this extension also.

Borings at the dam site were begun in July, 1904, and finished in June, 1905. They indicated a great mass of boulders, gravel, and sand extending to depths of 60 to 90 feet below the river-bed.

Shoshone Dam.—The design of the Shoshone Dam was closely related to that of the Pathfinder Dam. Both were high structures in narrow granite gorges. Studies on this design were made by George Y. Wisner, consulting engineer, and by John H. Quinton, also a consulting engineer, and the design adopted was the result of a long consultation on this problem by a board appointed for

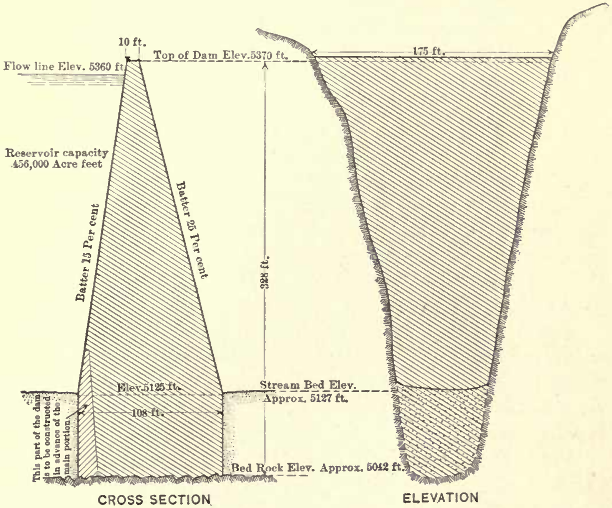


FIG. 124.—Section and Elevation of Shoshone Dam, Wyoming.

the purpose, and represents a compromise of several different ideas. The author was one member of the Board who favored a lighter section.

The design adopted provides for a top thickness of 10 feet, with a batter to stream-bed of 15 per cent on the reservoir face and of 25 per cent on the down-stream face. Both faces were made vertical below stream-bed. The axis was curved to a radius of 150 feet, forming an arch upon which the dam depends for stability. No natural deposits of sand or gravel were available near the dam site, and the specifications required both to be

manufactured of good, sound granite. The structure required was of concrete of the proportions 1:2½:5, in which sound stones or "plum rock" were to be imbedded, weighing from 25 to 200 pounds, to at least 25 per cent of the total volume.

A tunnel 500 feet in length, 10 feet square in section, was provided through the right abutment for the primary purpose of diverting the river during construction, and afterward employed for drawing water from the reservoir. A tunnel 20 feet square, on a 10 per cent grade, entered by a concrete lip west of the dam, was designed to serve as a spillway.

The construction of these works was let by contract, and work was started in October, 1905. The diversion tunnel was excavated, and preparations were made for diverting the river into it by building a diversion dam and a wooden flume to connect the dam with the diversion tunnel.

Work on the tunnel was stopped by high water in May, and on June 13 the largest flood of the season brought down large numbers of saw logs which greatly injured the diversion dam and destroyed the flume. The water floated it from place and the logs battered it into wreckage.

Financial difficulties prevented the contractor from resuming work, and in August the contract was suspended and a new contract executed by the bonding company which was surety for the failing contractor. The contract was later sublet by the bonding company.

Two cableways were installed, mounted on one tower below the dam, and on two towers above the dam, forming a letter V. These were used in excavating material from the river-bed, and also for handling material to go into the dam.

One No. 5 and one No. 7½ rock crusher were installed, and three sets of sand-rolls and one Jeffry pulverizer were used for making sand. Concrete was mixed with two No. 5 Smith mixers.

A steel truss bridge was built across the gorge from cliff to cliff about 40 feet above the river-bed and a little up-stream from the dam. A track was provided on this bridge to accommodate cars loaded with concrete and other materials.

Three large derricks were also installed for handling materials; two of them having 80-foot booms were located at the two abutments high enough to command the dam to completion, and one with a 60-foot boom a little lower on the left cliff, for use on

the lower portions of the dam. The larger derrick on the left abutment placed over 35,000 cubic yards of material in the dam.

In the spring of 1907, the new contractor undertook repairs

FIG. 125.—Foundation and Abutment of Shoshone Dam.

on the temporary diversion dam and work was resumed on the lining of the diversion tunnel.

The diversion dam was completed and a new flume connected it with the tunnel just before the advent of high water in May. The new flume was well ballasted and withstood the high water perfectly. Early in July, the flow of the river reached a discharge of 14,000 cubic feet per second and broke a saw-log boom some miles above, releasing a large number of saw logs which wrecked the diversion dam a second time on July 5.

After the high-water season, the temporary dam was rebuilt, but the time consumed thereby delayed the excavation of foundation into the winter. Concreting in the base of the dam was begun March 30, but on April 11 the pit was flooded by a freshet and the work was stopped. About the end of April, the flow de-

FIG. 126.—View of Shoshone Dam, Wyoming.

clined, the pit was pumped out, and concreting resumed; but on May 2 the river again rose and work was stopped for the flood season.

When the river was again diverted, it was found that the foundation pit had been filled with river gravel, sand, and mud, and its second excavation was necessary. This was begun on August 28, 1908, and was prosecuted so vigorously that concreting began one month later, and by the end of November the entire base of the dam was well above the river-bed. The advent of severe cold weather and the exhaustion of accumulated stocks of sand, gravel, and plum rock caused the suspension of operations for the winter. The extreme hardness of the granite rock

made the manufacture of suitable sand extremely difficult and subject to interruptions by the wear and breakage of machinery.

The stock bins were replenished during the winter, and concreting was resumed on March 16, 1909. In two weeks the wall was carried to an elevation above the top of the bridge, work was suspended for the flood season, and the summer floods poured over the dam to a maximum depth of 17 feet, without injury thereto.

Concreting was resumed September 1 and continued with various delays until the dam was completed January 16, 1910.

The winter was of unprecedented severity, and it became necessary to protect the concrete from frost by covering it with a huge tent and to heat the interior of this with a system of steam pipes. These, of course, though indispensable, greatly hampered the work and made it very expensive.

Scarcely less important were the delays from the chronic shortage of sand and plum rock. This was largely due to the extreme hardness of the rock, the consequent shortage of drill steel, and the difficulty of maintaining in working order the machinery for grinding the sand.

All of these difficulties, together with the extremely contracted room for operations in the narrow gorge, the great depth to foundation, and the large and fluctuating volume of water to be handled, combined to make the construction of the Shoshone Dam extremely hazardous, difficult, and expensive.

The lowest outlet from the Shoshone Reservoir is at elevation 5,134 feet above sea-level. It consists of two cast-iron pipes, each 42 inches in diameter, laid radially through the dam, imbedded in the concrete about low-water elevation in the river. At the discharge end the pipes were tapered to a diameter of 30 inches, and each is controlled by a pair of 30-inch gate-valves. The inverts of these pipes are at elevation 5,134 feet above sea-level.

The tunnel through which the river was diverted during construction has an entrance sill at 5,140 feet elevation. It is approximately 10 feet square and is controlled by duplicate sets of three cast-iron gates each 3 × 7 feet sliding on bronze faces. They are operated from a chamber above the tunnel, reached by an adit entering the cliff about 30 feet below the right abutment of the dam. The gages and operating mechanism are

practically duplicates of those at the Pathfinder Reservoir described on page 185. The operation is performed by oil pressure in a cylindrical tank, and the necessary power is furnished by a 50-horse-power gasoline engine. These gates are intended to operate under a maximum head of about 120 feet. A secondary tunnel is provided at elevation 5,233. It is 10 feet square on a 1 per cent grade, and will be controlled by balanced valves of the Ensign type.

CORBETT DIVERSION

The valley of the Shoshone consists of a series of terraces rising higher and higher above the bed of the river, which flows in a canyon cut in the gravels which form the terraces. Any diversion from the river therefore must be either by means of a high dam or a long tunnel built on a gradient less than the general slope of the benches. There being no suitable site for a high dam at the proper location, the tunnel method was the one adopted.

Water released from the Shoshone Reservoir flows down the river a distance of about 16 miles to the Corbett Diversion Dam, where it is diverted into a tunnel about 3 miles in length, which emerges into the Garland Canal. The Corbett Diversion Dam is of the hollow reinforced-concrete type, consisting of an inclined deck resting on buttresses. The deck is 30 inches thick, and inclines at an angle of 45 degrees. The buttresses are 2 feet thick and are spaced 12 feet apart in the clear. The structure rests on a platform of reinforced concrete 2 feet thick, founded on shale and gravel and extending down-stream a distance of about 40 feet from the dam. Three cut-off walls extend downward into the foundation under the dam.

The total height of the dam, including the base platform, is 18 feet and its length between abutments 400 feet. The right abutment joins an embankment 450 feet in length, reaching to the bluff and standing 8 feet above the masonry of the dam. At the left abutment are located a sluiceway and the headworks controlling the entrance to the Corbett Tunnel.

No suitable sand was found in the vicinity of the dam, and it was therefore necessary to manufacture the same by crushing cobble-stones from the stream-bed, which also yielded the necessary gravel.

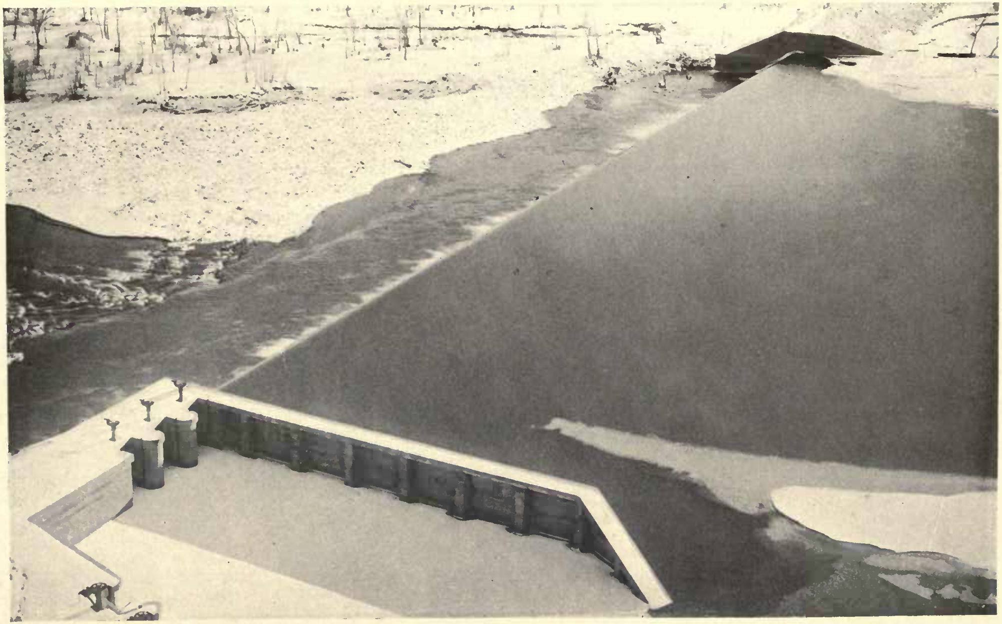


Fig. 127.—Corbett Diversion Dam and Sluiceway, Shoshone River, Wyoming.

The concrete was mixed in the proportions of 1:2½:5, and was conveyed from the mixer in cars of ½-cubic-yard capacity drawn by horses. The abutments of the dam and the sluiceway were built without diverting the river. For the main portion of the dam it was necessary to build a temporary dam of earth and gravel from the sluiceway diagonally up-stream to the opposite bank, and thus divert the low-water flow of the river through the sluiceway.

These works were constructed by contract in 1906 and 1907. The total cost was $130,125.48, the details of which are given in the table on opposite page.

About 12 miles below the Corbett Tunnel the main canal crosses a drainage line near Ralston, and here is found a reservoir of 2,100 acre-feet capacity to regulate the flow in the main canal, and it also serves to furnish a domestic water-supply throughout the year to Ralston and Powell.

DRAINAGE

There are few large valleys of the world that have been irrigated for any considerable time where important seepage problems have not developed, so that the necessity of drainage at some future time is to be in general anticipated, whenever a large irrigation system is undertaken. It seemed, however, that the Shoshone Project was likely to prove an exception. The irrigable lands have a slope of about 30 feet to the mile down the valley, and a slope toward the river of from 20 to 50 feet per mile, thus affording ready escape for surface water. Most of the lands are underlaid a few feet below the surface by coarse gravel extending to a great depth, and the entire tract is bounded on the south by the deep canyon of the Shoshone River, thus seeming to furnish convenient discharge for subsurface waters. Contrary to appearances, however, seepage appeared soon after irrigation began, and gradually spread until several thousand acres were more or less injured by ground water, and the damage continued to spread until drainage works were undertaken. Altogether about $425,000 has been spent upon drainage, a part being open, but most of them being covered tile drains of varying diameters. The drains have been very effective in relieving the seepage conditions on the project.

DAM AND HEADWORKS — CORBETT DAM — SHOSHONE PROJECT

Kind of Work	Unit	Quantity	Contractor's Cost		Contractor's Earnings		United States' Cost		Actual Cost	
			Total	Unit	Total	Unit	Total	Unit	Total	Unit
Excavation, Class 1	Cu. Yd.	7,865	$9,980.28	$1.269	$8,258.25	$1.05	$8,674.68	$1.103	$10,396.71	$1.322
" " 2	"	2,681	10,226.41	8.811	6,166.30	2.30	6,639.63	2.479	10,699.74	3.990
" " 3	"	1,454	10,964.69	7.541	6,761.10	4.65	7,325.19	5.039	11,528.78	7.930
Puddling..........	"	1,712	2,104.25	1.229	513.60	.30	558.23	.326	2,148.88	1.255
Concrete..........	"	4,950.59	48,753.24	9.848	40,842.37	8.25	67,368.82	13.611	75,279.69	15.209
Placing steel bar...	Lbs.	319,382	3,522.06	.011	4,790.73	.015	12,388.04	.039	11,119.37	.034
Setting gates, etc...	"	39,385	799.07	.021	1,181.55	.03	6,486.74	.....	6,104.26	.155
Extra work, cost 15 per cent........			2,848.05	.....	3,275.25	.....	3,275.25	.....	2,848.05	.....
Totals..........................			$89,108.05	.....	$71,789.15	.....	$112,716.58	.....	$130,125.48	.....

FIG. 128.—Outlet Gate Structure, Ralston Reservoir, Corbett Canal, Shoshone Project, Wyoming.

QUANTITIES AND COST OF CLOSED DRAINS CONSTRUCTED BY THE RECLAMATION SERVICE, SHOSHONE PROJECT, DECEMBER 31, 1915

		J	J-1	J-Ext.	K	L	M	N	O	P	A	I	Total
Length..........	Feet	27,095	3,765	3,191	41,490	51,474	18,796	11,356	8,893	8,375	16,950	60,473	251,858
Average depth...	"	8.5	8.3	9.3	8.5	9.4	9.2	9.4	9.1	8.5	8.2	8.6	....
Excavation......	Cu. Yd.	52,762	4,683	3,998	88,239	112,832	19,362	19,320	9,477	11,187	15,783	60,056	397,701
Cost, excavation..	"	$0.310	.400	.318	.254	.266	.322	.237	.346	.330	.281	.357	*.292
Backfill..........	"	47,537	4,683	3,998	85,922	122,565	18,670	19,320	9,477	11,187	15,537	57,737	396,436
Cost, backfill.....	"	$0.237	.142	.164	.168	.105	.175	.105	.111	.134	.182	.126	*.146
10-inch tile......	Feet	....	1,765	....	10,440	16,224	....	....	....	....	....	7,803	36,232
12- " "	"	10,795	2,000	3,191	17,950	14,988	....	4,940	3,078	8,375	....	25,550	90,867
15- " "	"	14,962	....	....	11,933	9,632	4,796	6,416	5,815	....	....	13,085	66,639
18- " "	"	....	....	....	....	10,630	13,650	....	....	....	16,950	13,495	54,725
Average Cost....	Per Ft.	$0.622	.497	.510	.550	.680	.710	.516	.498	.625	.622	.539	*.597
Manholes, cost...	Lin. Ft.	....	$0.043	.014	.032	.033	.025	.036	.042	.015	.017	.023	*.025
Machine........	....	Drag	Trench	Trench	Drag	Trench Drag	Trench	Trench Drag	Trench	Trench	Trench	Trench	....
Total Cost.......	....	$43,596	4,573	3,599	60,480	79,546	23,090	12,916	9,130	10,558	18,113	62,483	328,083
Cost per foot.....	....	$1.662	1.215	1.127	1.484	1.546	1.248	1.134	1.025	1.261	1.072	1.049	*1.317

* Average cost.

On the preceding page is a table of dimensions and costs of closed drains constructed to December 31, 1915.

The Shoshone Project was built under the general direction of H. N. Savage as Supervising Engineer. The construction of Shoshone Dam was under the immediate direction of D. W. Cole. The canal system and drainage works were constructed under project engineers Jeremiah Ahern, C. P. Williams, W. A. Stebbins, and J. T. Sanford, in succession.

CHAPTER XXIII

SETTLEMENT AND CULTIVATION

The engineering works described are but the means to the end contemplated by the Reclamation Law, which is the establishment of homes and the production of crops. A few pages on the latter subjects may therefore be of interest.

The principal obstacle to the successful development of large and expensive irrigation enterprises by private or corporate capital is the long, tedious, and expensive period of colonization and the subjugation of the desert soil by the colonists. Many a good project has bankrupted its builders by the accumulation of interest and maintenance charges before a sufficient number of settlers had cultivated the land and brought it to a point of profit. A recognition of this difficulty was doubtless the reason for the provision of funds for the construction of irrigation works without charging interest against the home-maker.

In the matter of settlement, the experience of the Reclamation Service has been somewhat similar to that of private investors. That is, settlement has been quick in some localities and slow in others. Where settlement was slow, the Government project had the advantage of not having to add interest to the investment.

The greatest embarrassment suffered by the Government projects regarding settlement, however, arose from the influx of settlers who filed upon the land during the period of survey, before construction began or the project was even declared feasible. In some cases the project was not taken up at all. In others, part of the lands settled were excluded owing to limitations of water supply or physical difficulties, and in most cases several years elapsed before the completion of storage or other heavy works by which water could be delivered, and the settler was impoverished and discouraged in the long waiting process. This defect of the law was remedied by an amendment, passed in 1910, requiring the Secretary to exclude settlers until water could be delivered. But this gave no great relief, as all the projects having this trouble were already settled.

In general, where settlement on public land is slow, it is the aim to keep the extension of the works only moderately in advance of settlement, and no great areas of public land are now open to settlers on the various projects.

Difficulties of the Settlers.—The principal difficulty with which the average settler on the reclamation projects has to contend is the lack of sufficient capital. In some cases the settler may originally have had considerable capital, but his lack of experience, or other misfortune, has operated to his disadvantage until his funds have been practically exhausted, and after he has acquired the necessary experience he is often unable to recover his standing for the lack of the necessary capital.

Some cases have occurred where men of little capital and no experience have settled on reclamation projects and by their perseverance and ability combined with favorable conditions have succeeded in building up homes worth thousands of dollars, while some of their neighbors similarly situated, who began with considerable capital and perhaps greater experience, have not achieved equal success.

The cases of success with little capital, however, are relatively few and are likely to be misleading if often quoted. In general, the settler should have from one to three thousand dollars in order to develop a homestead of forty acres promptly and economically, and for larger homesteads larger capital is necessary for the best results. Care, skill, industry, and perseverance are all equally as necessary as capital, and without these or any one of these failure is almost certain.

This lack of capital is felt more acutely the larger the area acquired or attempted to be cultivated. The instances of success with small capital, especially in the case of inexperienced settlers, are confined almost entirely to small holdings of forty acres or less, and perhaps no one circumstance has operated so strongly to handicap settlers in making a success upon Government projects as the attempt to hold and improve too much land.

One of the most serious and far-reaching handicaps to the success of a settler was the provision of the law and rulings thereunder permitting settlers to file upon lands to be irrigated, in tracts of 160 acres, even before the surveys were made or decision reached regarding the feasibility of the project.

On the projects that were actually taken up, the public land

in many cases was occupied by entrymen who had each filed upon 160 acres, endeavoring to hold a homestead during the years of survey and construction, which was ultimately delayed from lack of funds or other causes. The settlers exhausted all their available funds in living expenses and when the water was ready for delivery were utterly unable to prepare the land properly or to install the improvements and equipment necessary for success on an irrigated farm. In every case the prospective value of the land with a water right was greater than the cost of the water right, so that the settler became anxious to hold his entire tract of 160 acres or as much thereof as possible. This pressure exerted upon the local men and upon the Washington authorities through Representatives and otherwise led to the establishment of farm units, usually eighty acres or more, where half the size would have been more appropriate, and the impoverished settlers were burdened the first few years with charges upon a large area of land, none of which they were able to cultivate properly, owing to lack of preparation and of equipment; in short, they were attempting the impossible.

A typical example is on one project where the average irrigable area of the holdings is sixty-five acres, while the average cultivated area is twenty-five acres. The average farmer is thus struggling under the dead load of charges upon forty acres, which he is unable to use, but which are burdensome in the matter of fencing and otherwise. Where a farmer has an excess area, he is almost sure to cultivate more land than he can properly level and provide with irrigating ditches, so that he obtains inferior results even from the acreage which he does cultivate.

The Huntley Project in Montana is conspicuously successful so far as individual prosperity is concerned. This project was handicapped by the cold climate, the usual drawbacks of refractory soil, and the characteristic desert difficulties, but it was opened under a special law which gave the Secretary wide discretion, and policies were adopted which could not be applied to other projects owing to legal requirements. The size of the farm unit was in general made forty acres. Settlers were not permitted upon the land until the water was ready for delivery, and when settlement was invited each settler was obliged to pay $1 per acre to the Indian tribe as partial payment for the land and also ten per cent of the water charge at time of entry.

These substantial payments eliminated the impecunious speculator; the settler was not compelled to live for years upon an arid homestead without water and thus dissipate his means and his patience, and he was not permitted to take more land than was necessary for his livelihood. Thus were eliminated the three principal causes of failure upon other projects.

The Shoshone Project and many other projects illustrate strikingly the contrast between large and small holdings. On those projects, homesteads near railroad stations are generally made forty acres, while farther out they contain eighty acres of irrigable land and sometimes more, up to a limit of 160 acres. In general, the individuals with the small holdings, having less tax upon their resources for improvements and water charges, have been successful, while their neighbors similarly situated, but with larger holdings, have been unable with their means to cultivate any larger area of land during the first few years when the struggle is on, and have had the additional burden of double the water charges and heavier costs for fencing and other improvements. The results have shown a larger percentage of success and general prosperity upon the small unit.

Values Created.—In general, it may be said that the material values created by the construction of irrigation works under the Reclamation Law have been far greater than the amount expended upon the works. These values are reflected almost entirely in the rise in value of land, and if this increase of land value, or any large fraction of it, could be promptly returned to the Government through any legal process, it would afford a large profit on the investment.

So long as the value that attaches to land goes into private pockets there appears to be no escape from the fact that the benefits of all public improvements, including irrigation works, inure to the benefit of landowners almost exclusively.

The problem of excessive holdings was early attacked by the officials of the Reclamation Service, who recognized the necessity of forcing the subdivision of large holdings and adopted a rule by which prior to taking up the project the owners of excess areas were required to execute an instrument binding themselves to sell the excess holdings in small areas to persons eligible to acquire water rights, failing which the Government was given the right to enforce its sale at auction at the specified time. Such con-

tracts have been enforced in a few instances, but in others have led to long-drawn-out litigation with no substantial result. At best, this proviso does not prevent the selling of the land at speculative prices which load the settler with debt and jeopardize his success.

That the benefits of the Government construction would incidentally accrue to private landholders was recognized by Congress when it prohibited the sale of water rights to a larger area than 160 acres in one holding, and this was evidently an effort to prevent the acquisition of an unfair proportion of the benefits by one landholder. The provision, however, has no effect on the distribution of the benefits to towns and cities in the vicinity whose business has been largely increased by the construction of the irrigation project, resulting often in doubling or trebling land values in those cities in a very short time. The reclamation law affords no means of recovering those values to the reclamation fund. Section 12 of the reclamation extension act sought to strengthen the hands of the Government by requiring that private holdings in excess of 160 acres in new projects shall be subdivided and sold at such a price as the Secretary of the Interior may designate, and if not so subdivided shall be excluded from the project. This provision affords little relief, as it cannot be applied to projects already taken up; and wherever applied, though it may limit the price at which the present holder can sell his land, the purchaser who buys from him may sell to the actual settler at such price as he is able to extort. It may result in the introduction of a middleman without protecting the actual settler. The exclusion of the land, however, does not prevent the landowner from holding it at a price that discounts the added value conferred by prospective water rights, for the logic of the situation enables him to convince the purchaser that once the land is in the hands of a small holder the law would not prevent the purchase of water right, and the economy of so including the area within the project would induce the Government to sell him such a water right.

A more effective means of compelling large landholders to bear their just proportion of the cost of the project is made available by the passage in various States of laws providing for the formation of irrigation districts. Under such laws it is generally possible, where a majority of the landowners desire to provide funds for

irrigation works, to force the minority to assume their fair share of the burden through the medium of taxation.

Soil Conditions.—It has been customary for the Reclamation Service to secure the best soil experts available, usually from the Bureau of Soils, to examine the soil of each contemplated project and on the basis of their examination to classify the lands into irrigable and non-irrigable land. Necessarily the dividing line between fertile and infertile soil is very indefinite, and the best of opinions will differ and are apt to be in error. Some cases have occurred where tracts have been included in the irrigable area that have presented new or unexpected difficulties by reason of their coarse, sandy character, requiring an excessive amount of water and attention, or, on the other hand, of their close, heavy texture or the presence of too much alkali. Such conditions render more difficult the subjugation of the soil, which at best in a desert region is difficult with the limited means at the disposal of the average settler.

In some cases also the rise of ground water, resulting from over-irrigation or seepage from canals, has destroyed the fertility of lands otherwise fertile. The latter difficulty has been remedied largely by the construction of drainage works, but not until after some hardship had been suffered by some of the settlers.

It has been the practice of the department to suspend payments upon lands that have been injured by ground water or otherwise proved to be infertile. These difficulties are somewhat sporadic, and would usually not be important if not aggravated by the condition previously set forth of the lack of capital of the settler beset with many burdens.

The Extension Act.—Recognizing the difficulties above enumerated, Congress undertook in 1914 to meet the situation by the passage of the reclamation extension act, which, among other changes in the existing law, increased the term of payment for water right from 10 years to 20 years, making the average payment 5 per cent of the total charge, and so graduating this as to make the payments lighter than this in the early years.

This law has resulted so far in inspiring new courage in many of the settlers and materially assisting them to get on their feet, not only by leaving their capital with them, but by improving their credit through brightened prospects. While it is too early to predict all results with accuracy, it can safely be said that the

Reclamation Fund Accretions from the Sale of Public Lands, and Net Investment, by States

States	Receipts from Sale of Public Lands to June 30, 1916	Net Investment to June 30, 1916
Arizona	$1,430,751.22	$17,393,367.27
California	6,112,831.91	2,979,219.89
Colorado	7,763,626.96	8,854,743.51
Idaho	5,680,195.39	16,572,239.83
Kansas	1,005,257.66	376,240.79
Montana	11,267,402.63	11,317,635.01
Nebraska	1,868,670.15	4,797,893.49
Nevada	656,467.25	5,786,828.44
New Mexico	4,521,322.88	4,681,546.66
North Dakota	12,114,994.05	1,973,885.18
Oklahoma	5,850,169.06	79,389.84
Oregon	10,836,127.48	4,102,849.93
South Dakota	7,252,799.95	3,384,398.76
Texas	....	2,209,086.96
Utah	2,108,556.93	3,095,629.93
Washington	6,933,957.37	8,054,533.50
Wyoming	4,985,200.72	6,367,332.91
Secondary projects	....	124,634.17
Total	$90,388,331.61	$102,151,456.07

Irrigation and Crop Results on Government Projects, 1915

Project	Irrigable Acreage	Irrigated Acreage	Cropped Acreage	Value of Crops	
				Total	Per Acre Cropped
Salt River	219,691	179,350	171,832	$3,661,769	$21.31
Yuma	72,440	27,857	25,101	873,721	34.81
Orland	20,320	8,928	6,930	220,422	31.81
Uncompahgre Valley	65,000	41,463	40,553	1,044,915	25.76
Boise	150,000	76,705	69,818	1,526,873	21.87
Minidoka	120,000	83,562	77,008	1,725,515	22.41
Huntley	30,813	18,203	18,185	535,363	29.41
Milk River	22,200	4,192	3,887	51,249	13.18
Sun River	16,326	4,261	4,243	80,000	19.00
Lower Yellowstone	42,329	12,656	11,990	194,011	16.18
North Platte	129,714	70,007	68,130	1,263,617	18.55
Truckee-Carson	65,000	40,295	38,495	592,523	15.39
Carlsbad	24,796	13,470	11,322	245,684	21.70
Hondo	3,330	1,294	1,287	17,778	13.81
Rio Grande	45,000	33,876	32,246	1,103,389	34.22
Umatilla	17,000	5,306	3,603	104,653	29.04
Klamath	38,000	27,254	27,254	377,488	13.85
Belle Fourche	78,591	44,067	43,063	462,050	10.72
Okanogan	10,099	7,800	4,814	254,425	52.60
Yakima: Sunnyside	82,757	66,607	54,919	2,750,326	50.08
Tieton	34,000	22,000	18,100	668,650	37.00
Shoshone	42,816	25,753	24,833	410,031	16.51
Totals, reclamation projects	1,472,772	856,778	....	......	....

chance of success on many of the projects is improved, both from the standpoint of the settlers' welfare and of the recovery of the reclamation fund from the lands benefited.

Receipts and Investment by States.—The table on page 397 gives a statement of additions to the reclamation fund from the sale of public lands, by States, and also shows the net investment of the Government for irrigation work in each of the reclamation States.

The area for which the Reclamation Service was ready to deliver water in 1916 was in round numbers about 1,500,000 acres, while the area actually irrigated was about 900,000 acres. Of the difference, 600,000 acres, not to exceed 5 per cent, was unentered public land. The following shows the growth in seven years:

PROGRESSIVE RESULTS OF RECLAMATION

Year	Irrigable Acreage *	Irrigated Acreage	Irrigated Farms	Cropped Acreage	Crop Value
1909.......	730,000	382,000	9,000	......	....
1910.......	880,000	475,000	12,000	415,000	$12,500,000
1911.......	1,015,000	560,000	14,000	470,000	13,000,000
1912.......	1,160,000	645,000	15,000	590,000	14,500,000
1913.......	1,200,000	700,000	16,000	650,000	16,000,000
1914.......	1,250,000	770,000	18,000	700,000	16,500,000
1915.......	1,470,000	857,000	20,000	800,000	19,000,000

* Area Reclamation Service was prepared to supply water.

Collections.—The two tables below give information as to collections that have been made under the reclamation operations.

ANALYSIS OF CASH COLLECTIONS TO JUNE 30, 1916

Sources	Total to June 30, 1916
Miscellaneous sales..................................	$1,933,840.61
Miscellaneous services..............................	4,428,000.80
Temporary water rentals............................	3,330,319.89
Power and light......................................	1,040,524.57
Transportation refunds..............................	305,102.27
Forfeitures by bidders and contractors.................	78,908.71
Water-right construction charges......................	4,146,630.35
Water-right operation and maintenance charges..........	2,448,095.09
Over disbursements..................................	38,762.36
Total..	$17,750,184.65

Collection of Water-Right Charges by Projects to June 30, 1916

State and Project	Construction Charges	Operation and Maintenance Charges	Total
Arizona: Salt River	$100,000.00	....	$100,000.00
Arizona-California: Yuma	270,785.26	$61,090.33	331,875.59
Idaho: Minidoka	441,782.68	310,459.62	752,242.30
Kansas: Garden City	142.50	104.50	247.00
Montana: Huntley	270,173.02	115,513.70	385,686.72
Sun River	102,685.36	42,407.44	145,092.80
Mont.-N. Dakota: Lower Yellowstone	35,872.20	36,793.97	72,666.17
Nebraska-Wyoming: N. Platte	352,599.87	330,976.03	683,575.90
Nevada: Truckee-Carson	296,767.26	191,944.93	488,712.19
New Mexico: Carlsbad	140,368.89	139,816.49	280,185.38
North Dakota: N. Dakota Pumping	8,058.05	13,307.15	21,365.20
Oregon: Umatilla	206,338.23	75,202.05	281,540.28
Oregon-California: Klamath	291,082.86	137,127.96	428,210.82
South Dakota: Belle Fourche	168,078.68	131,448.95	299,527.63
Utah: Strawberry Valley	19,827.87	5,129.23	24,957.10
Washington: Okanogan	24,622.55	36,294.89	60,917.44
Wash.: Yakima Storage	200,000.00	....	200,000.00
Yakima Sunnyside	579,422.79	542,674.41	1,222,097.20
Yakima Tieton	269,388.61	149,880.44	419,269.05
Wyoming: Shoshone	268,633.67	127,923.00	396,556.67
Total	$4,146,630.35	$2,448,095.09	$6,594,725.44

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